U.S. Department
of Transportation

**Federal Railroad
Administration**

Technical Supplement

**to the
Draft Environmental Impact Statement
of the
Proposed Rule for
the Use of Locomotive Horns
at Highway-Rail Grade Crossings**

Office of Railroad Development
Washington, D.C. 20590

December, 1999

Prepared With:

Harris Miller Miller & Hanson, Inc.
15 New England Executive Park
Burlington, MA 01803

&

Parsons Transportation Group, Inc.
1133 15th Street NW
Washington, D.C. 20005

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. SUMMARY

The assessment of the potential noise impact of the proposed, Use of Locomotive Horns at Highway-Rail Grade Crossings rule, relies on criteria for noise impact developed by the Federal Railroad Administration (FRA). The criteria are based on research conducted by the U.S. Environmental Protection Agency (EPA). Impact at each current whistleban crossing was assessed by comparing the horn sounding environment to a quiet zone environment. Severity of noise impact from horn sounding was rated according to the relative increase in noise levels.

A generalized horn sound model was developed by Harris Miller Miller and Hanson (HMMH) under subcontract to Parsons Transportation Group for FRA. The model includes sound source levels based on measurements and previous studies, sound exposure calculations based on train speeds and the number of trains passing during day and night at each crossing, propagation of sound to nearby neighborhoods based on typical suburban terrain and building configurations, and community reaction estimation based on EPA and FRA noise research. The computer model uses relevant data for each grade crossing under study, such as number of trains per day and night, speed, and number of tracks, drawn from the US DOT /AAR Grade Crossing Inventory. The model then calculates noise impact areas at each location represented by five-sided polygons. Two zones of noise impact are defined, impact, and severe impact as a subset of impact. In the impact zone, the change in the sound level is expected to be noticeable to most people, but may not be sufficient to cause strong, adverse reactions from the community. In the severe impact zone, a significant percentage of people are likely to be highly annoyed by horn sounding.

The estimated total population residing within the two impact zones at each current whistleban crossing represents a worst case measure of the potential annoyance from the proposed rule. Impacted population at each crossing was estimated by Parsons Transportation Group using a geographic information system (GIS) by overlaying noise polygons with census block data. Finally, the horn noise model was used to assess the effects of other provisions of the proposed rule on locomotive horns that would benefit all communities with public highway-rail grade crossings. A typical crossing drawn from data on 147,653 crossings was modeled and the resulting population benefits estimated using 1990 census tract data.

2. CHARACTERISTICS OF TRAIN HORNS

Analysis of the characteristics of train horns at grade crossings has been the subject of safety research programs and environmental assessments. Information on locomotive horn systems and the relevant research into horn sound characteristics is summarized in this section.

2.1 Horn Systems

Two domestic manufacturers of air-operated locomotive horns dominate the North American market. They are:

1.   Nathan Manufacturing Division of the Windham Machine Co. Inc.
     S. Windham, CT
2.   Leslie Controls, Inc.
     Tampa, FL.

Both companies manufacture very similar horn designs. The Nathan units are manufactured under license to Airchime Manufacturing Company of Langley, B.C., Canada. Both types of horns consist of die-cast aluminum bells mounted to a housing that contains a cushioned diaphragm and channels for compressed air. The bells and housing are then fastened to a base that mounts to the locomotive and that contains the connection point for the locomotive air supply. Air pressures for both makes of horns range from 40 to 140 psi. Sound is generated from the action of compressed air which causes vibration of a metal diaphragm. Both companies supply horns with one to five individual horns or "chimes" in a cluster. The length of the bell controls the frequency of the chime. Sound level and air consumption are controlled by varying the input air pressure and using a restrictive orifice either in a plate (Nathan) or in a dowel pin (Leslie)[1,2]. The engineer controls the sounding of a horn by either pressing a button or pulling on a lever attached to a spring-loaded valve. A schematic of a typical train horn system is shown in Figure 2.1.
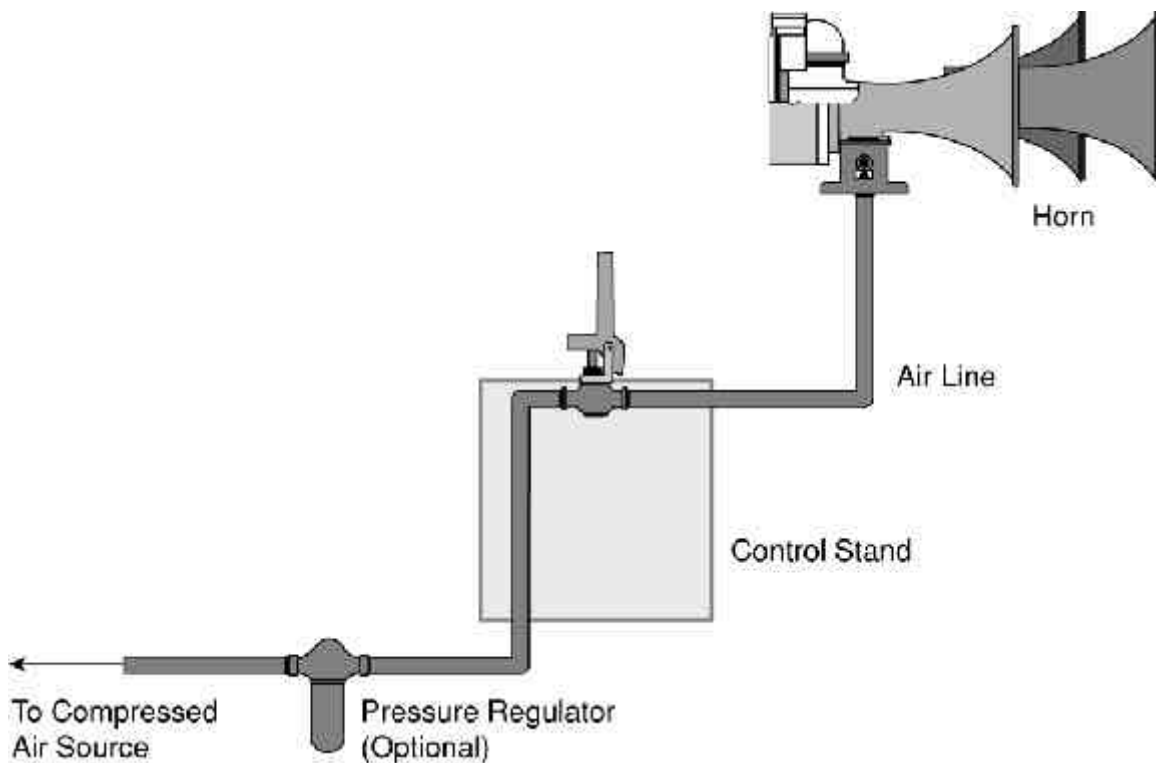
Figure 2.1. Schematic of Train Horn System

---

[1] Product Literature of Nathan Manufacturing Div. of Windham Machine Co., Inc.

[2] Product Literature of Leslie Controls, Tampa, FL.

Curves of air consumption and air pressure versus sound level for several horn models from both manufacturers and frequencies for multi-chime horns are given in product literature. Multi-chime horns from Nathan and Leslie are made so that any bell is easily reversible. Typical sound levels of horns from both manufacturers are given below in Table 2.1.

Table 2.1. Locomotive Horn Data

Manufacturer	Model	Air Pressure (psi)	A-weighted Sound Level @ 100 feet (dBA)
Nathan	K-5-L	90	113
Nathan	K-3-L	90	114
Leslie	RS-3	100	114
Leslie	RS-5	100	115

Both three- and five-chime horns from Nathan and Leslie are in common use. A report by Keller and Rickley at the Volpe National Transportation Systems Center (Volpe Center) includes measured levels and directivity of two Leslie three-chime horns and one five-chime Nathan unit.[3]

The sound level from locomotive horns can be affected by the mounting location on the locomotive. For example, Keller and Rickley[4] measured levels from a Leslie RS-3-RF unit mounted on a Union Pacific Dash-8 locomotive roughly in the middle of the hood behind an auxiliary electrical cabinet. Directivity measurements showed that the level in front of the locomotive on its axis was approximately 6 dB lower than at the sides, and approximately 8 dB lower than the level measured at the rear. One railroad has several different mounting positions: some are located between 9 and 21 feet from the front of the short hood. On many of their locomotives, there is a horn mounted on each end of the unit to allow for operations in either direction. However, several classes of locomotives have the horns mounted in the center.

2.2 Noise Characteristics

Characteristics of noise environments near grade crossings have been the subject of several recent research programs. Locomotive horn noise has been studied for two primary reasons. The first is

---

[3] Keller, A., and Rickley, E. The Safety of Highway-Railroad Grade Crossings: Study of the Acoustic Characteristics of Railroad Horn Systems. Report No. DOT/FRA/ORD-93/25, June 1993.

[4] *Ibid.*

safety for motorists approaching railroad grade crossings, and the second is to determine noise impacts in the communities neighboring grade crossings.

2.2.1 Previous Studies

The Federal Railroad Administration is currently engaged in a research program entitled "Safety of Highway-Railroad Grade Crossings." This program deals primarily with safety issues, but two of the three reports that have been published also include studies of community noise impact from locomotive horn noise. All three reports give measurements of locomotive horn noise.

In the first report in the series, Keller and Rickley[5] present sound level measurements of three different locomotive horns mounted in their normal operating position on top of stationary locomotives. Measurements of a wayside horn mounted at its intended height above the ground are also given. The measurements of the locomotive horns were made in Iowa, Massachusetts, and Florida. Locomotives were provided by the Union Pacific Railroad, the Massachusetts Bay Transportation Authority (MBTA), and the Florida East Coast Railroad.

The second report in the series, written by Multer and Rapoza[6], is a field evaluation of wayside horns as an alternative to locomotive horns. The study includes sound level measurements of both locomotive horns and wayside horns at 14 sites surrounding three grade crossings in Gering, Nebraska. Sites were chosen based on how annoyed residents were expected to be, as predicted by their proximity to the grade crossings. Measurements were also made of wayside horns at the same grade crossings. The report presents an estimate of community noise impact from locomotive horns and a survey of the community to see how predicted annoyance compared with actual annoyance. The report also gives a survey of driver behavior at the grade crossings.

The third report in the series is entitled "The Effectiveness of Railroad Horn Systems."[7] In this study, the authors, Rapoza, Raslear, and Rickley, address the effectiveness of locomotive horn systems and their resulting impact on the community. Locomotive horn sound data was collected at six grade crossings along the Florida East Coast Railroad's mainline. Insertion loss and interior sound levels of several late model automobiles were measured to determine if the horns provided an effective warning to motorists. Also addressed is the distance at which the signaling cycle should begin to minimize community noise exposure.

---

[5] *Ibid.*

[6] Multer, J., and Rapoza, A. The Safety of Highway-Railroad Grade Crossings: Field Evaluation of a Wayside Horn. Report No. DOT/FRA/ORD XXX, February 1997.

[7] Rapoza, A., Raslear, T. G., and Rickley, E., The Safety of Highway-Railroad Grade Crossings: The Effectiveness of Railroad Horn Systems, Vol II. Report No. DOT/FRA/ORD XXX, August 1997.

Measurements and theoretical models of horn sound have also been made to assess community noise impact. Most of this work has been done as part of the environmental impact assessment process for proposed railroad mergers. One study by Richard Carman of Wilson, Ihrig & Associates gives a theoretical model of locomotive horn noise.[8] The model assumes that the horn is blown continuously beginning at a fixed distance from the grade crossing until the grade crossing is reached. As such this model does not take into account the signaling cycle and would tend to over predict sound exposure levels. No correlation with measured levels is given.

The environmental reports issued as part of the analysis of impact expected from railroad mergers typically include measurements of train noise both at grade crossings and at line segments away from grade crossings. Normally these measurement programs present maximum sound levels from locomotive passbys as well as from the railcars alone.

Harris Miller Miller & Hanson Inc. (HMMH) made measurements of Conrail and CSX trains at five sites in Ohio in conjunction with the environmental report in support of the Surface Transportation Board's assessment of the acquisition of Conrail by CSX and Norfolk Southern.[9] Similar measurements of Conrail and Norfolk Southern trains were made by William Thornton Associates for the other part of the Conrail merger[10]. Thornton's measurements were made in North Carolina to document sound levels from Norfolk Southern freight trains.

HMMH also made sound level measurements of Illinois Central and Canadian National freight trains as part of the environmental assessment for the proposed merger of these two railroads.[11] This program, like those described above, included horn sound levels at grade crossings as well as at sites away from crossings.

HMMH conducted measurements of Burlington Northern freight train sound in Carrollton, Texas as part of a project to document impact on a housing project adjacent to a grade crossing in the City of

---

[8] Carman, R. A. Community Noise Model for Train Warning Horn. Presented at the Acoustical Society of America and Acoustical Society of Japan Joint Meeting, December 1996.

[9] Dames & Moore, Burns & McDonnell. Environmental Report, CSX Corporation and CSX Transportation, Inc., and Norfolk Southern Corporation and Norfolk Southern Railway Company-Control and Operating Leases/Agreements-Conrail, Inc. and Consolidated Rail Corporation. Finance Docket No. 33388, before the Surface Transportation Board, June 1997.

[10] Dames & Moore, Burns & McDonnell. Environmental Report, CSX Corporation and CSX Transportation, Inc., and Norfolk Southern Corporation and Norfolk Southern Railway Company-Control and Operating Leases/Agreements-Conrail, Inc. and Consolidated Rail Corporation. Finance Docket No. 33388, before the Surface Transportation Board, June 1997.

[11] Harris Miller Miller & Hanson Inc., unpublished data, June 1998.

Carrollton. The measurements were made on two separate occasions, over a period of two days each. The data were subsequently used in determining source levels for the Burlington Northern/Santa Fe Railroad merger noise assessment.

2.2.2 Sounding Practices

The Sound Exposure Level (SEL) of the locomotive warning signal pattern is dependent both on the duration of the horn events and their sound level. As shown in the following sections, although the horn levels are relatively predictable as discussed above in Section 2.1, the signaling patterns, including the horn sounding durations, are not.

There is no FRA mandated signaling pattern for warning people at grade crossings. In fact, the Code of Federal Regulations[12] states that "Locomotive's audible warning device shall be activated in accordance with railroad rules regarding the approach to a grade crossing." The most commonly used signaling pattern for sounding a locomotive horn at grade crossings is long-long-short-long. The engineer is required to sound the horn 1/4 mile before the grade crossing or at the whistle post (if one is present) and continue the pattern until the crossing is occupied by the lead locomotive or lead car (in pusher service). There is no specified duration for either the horn blow components or for the intervals between the components.

Rapoza, Raslear, and Rickley[13] made measurements of the durations of horn blows as well as the levels of each component for 12 train events. They found that the duration of the long component varied from 2 to 9 seconds. The duration of the short component ranged from 1 to 4 seconds. In addition, they observed that the A-weighted sound level of the short component tended to be about 4 dB below that of the long components.

HMMH[14] observed durations for the short components to range from 1 to 3 seconds, while the long component varied from 1 to 7 seconds. In addition, the point at which the engineer started the horn sounding cycle varied from 362 to 1,940 feet from the grade crossing. The overall length of the signaling cycle varied from 8 to 41 seconds. There appeared to be no correlation of overall cycle length (and therefore the distance before the grade crossing) with train speed or presence of whistle post. One of the two railroads observed had no whistle posts.

---

[12] 49 CFR Ch.11, 234.105(d).

[13] Rapoza, A., Raslear, T. G., and Rickley, E., Safety of Highway-Railroad Grade Crossings: The Effectiveness of Railroad Horn Systems, Vol II. Report No. DOT/FRA/ORD XXX, August 1997.

[14] Harris Miller Miller & Hanson Inc., unpublished data collected for Illinois Central/Canadian National Railroad merger, June 1998.

During the measurements made specifically for this program, HMMH[15] observed that many engineers did not follow the long-long-short-long pattern, but instead sounded the horn in a seemingly random pattern, adjusting the length of the cycle and the pattern itself to make sure the horn was sounding as the lead locomotive passed into the grade crossing. Typical time histories of horn sounding patterns measured near a grade crossing in North Carolina are shown in Figure 2.2.
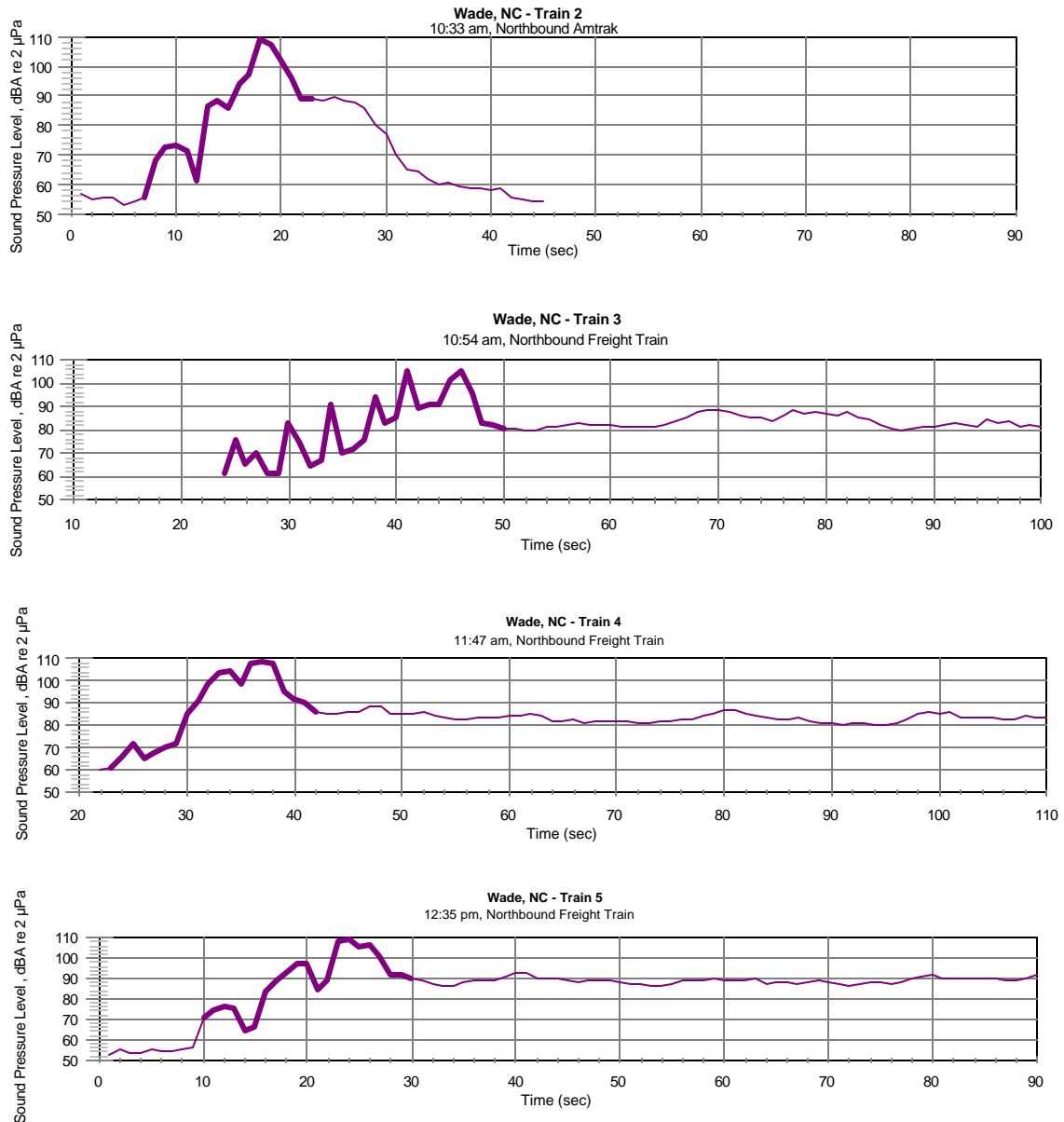
Figure 2.2. Typical Time Histories of Horn Sounding at a Crossing in North Carolina

[15] Personal communication with David Towers of Harris Miller Miller & Hanson Inc.

Control of the signaling pattern may be one way to reduce community noise impact without compromising safety. Automatic horn sequencers are available that control the whistle pattern in relation to train speed. However, there is no requirement that these devices be used.

In summary, then, only two consistent features of grade crossing warning signals have been observed. One is the long-long-short-long sounding pattern (and even this is not always used), and the second is the sounding of the horn through the grade crossing. The duration of the long and short components, the spacing between the components, and the overall length of the signaling cycle (and therefore the point at which the cycle begins) all seem to be random.

2.2.3 Measurement Data

The studies mentioned in section 2.1 contain much relevant measurement data that has been distilled from each source and is presented in Appendix C. The sound level data presented in the Volpe Center report, "Study of the Acoustic Characteristics of Railroad Horn Systems" consists of measurements made of horns on three stationary locomotives: a Union Pacific Dash 8, an MBTA F-40 PH-2M, and a Florida East Coast GP-40.[16] The three locomotive horn models represented are the Leslie RSL-3L-RF, the Nathan K-5-LA, and the Leslie RS-3L, respectively. The report gives both directivity and spectral information for all three of the horns. Of particular interest is the effect of mounting location on the directivity of horns. The Leslie RSL-3L-RF (a three-chime unit) was mounted on a General Electric Dash-8-40CW locomotive. This model was set up with two chimes facing forward (i.e., towards the short hood) and one facing the rear. The horn was mounted roughly in the center of the locomotive behind an auxiliary electrical cabinet. The barrier effect of the cabinet caused the horn level measured in front of the locomotive to be approximately 6 dB lower than at the sides and about 8 dB lower than at the rear. Maximum A-weighted levels as well as L_{eq}'s are presented in the appendices of the Volpe Center report. A-weighted maximum levels and durations for each component of a typical long-long-short-long grade crossing signaling cycle are also provided for each horn.

In Multer and Rapoza's report, "Field Evaluation of a Wayside Horn", measurements of locomotive horn sound were made at 14 sites surrounding three grade crossings in Gering, Nebraska.[17] The railroad was the Union Pacific and all horns were Lesley three-chime units. At least six events were recorded at each microphone position. Speed was recorded with a Doppler radar gun.

---

[16] Keller, A., and Rickley, E. The Safety of Highway-Railroad Grade Crossings: Study of the Acoustic Characteristics of Railroad Horn Systems. Report No. DOT/FRA/ORD-93/25, June 1993.

[17] Multer, J., and Rapoza, A. Safety of Highway-Railroad Grade Crossings: Field Evaluation of a Wayside Horn. Report No. DOT/FRA/ORD XXX, February 1997.

Measurements were made only when the train speed was between 22 and 28 mph. No data was taken if there was any precipitation or snow cover. At each grade crossing site, the microphone was located 100 feet from the tracks. The data gives L_{eq}, L_{max}, L_{min}, and SEL, as well as train speed, time and meteorological data.

In "The Effectiveness of Railroad Horn Systems," Rapoza, Raslear, and Rickley made train passby sound level measurements at six sites in Jacksonville, Florida.[18] Two train events were recorded at each site. At each site a digital recording system was placed 200 feet from the track centerline and a sound level meter was placed 50 feet from the track. (At one site, these locations were at 150 feet and 75 feet respectively due to space restrictions.) For each of the 12 train events, the signaling cycle is presented showing maximum levels and duration for each horn blow. The SEL for the complete cycle is also shown. Spectral time histories and frequency spectra at A_{max} for each event are also presented.

All sound level data in the merger impact assessments give locomotive SELs, maximum A-weighted levels for locomotive and railcars, and finally L_{eq}s for the railcar passbys. Spectral information is generally not shown.

A summary of the grade crossing measurement sites is presented below in Table 2.2, and a summary of all the SEL measurements made at grade crossings is shown in Table 2.3.

Table 2.2. Grade Crossing Measurement Sites

	Location	Railroad Measured	Date of Measurement	Number of Trains
HMMH, Illinois and Indiana	Monee, IL	IC	May 1998	7
	Chebanse, IL	IC	May 1998	7
	Highland, IN	CN	May 1998	7
	Crumstown, IN	CN	May 1998	15
HMMH, Ohio	Powell, OH	CSX	November 1996	6
	Fostoria, OH	CSX	November 1996	7
	Sandusky, OH	Conrail	November 1996	12
	LaRue, OH	Conrail	November 1996	9
	Leipsic, OH	CSX	November 1996	3
Volpe Center, Florida	Jacksonville, FL	FEC	July 1992	12
Volpe Center, Nebraska	Gering, NE	UP	November 1995	24
William Thornton, Assoc. North Carolina	China Grove, NC	NS	November 1996	6
HMMH, Texas	Carrollton, TX	BN	December 1992/ March 1993	23

---

[18] Rapoza, A., Raslear, T. G., and Rickley, E., The Safety of Highway-Railroad Grade Crossings: The Effectiveness of Railroad Horn Systems, Vol II. Report No. DOT/FRA/ORD XXX, August 1997.

Table 2.3. Sound Exposure Levels in dBA at Grade Crossings - Normalized to 100 Feet from Track Centerline

Average	Illinois Central	Canadian National	CSX	Conrail	Florida East Coast	Union Pacific	Norfolk Southern	Burlington Northern
	111.4	110.9	108.7	107.4	109.9	104.3	107.6	110.6
	102.4	109.2	115.0	104.8	111.7	104.9	106.1	114.6
	106.2	115.0	101.6	99.9	102.8	106.0	106.6	113.6
	108.3	116.0	101.7	103.8	103.4	101.5	109.6	114.6
	103.8	117.2	110.8	108.4	96.2	106.1	103.7	114.6
	111.9	112.9	108.6	103.3	100.6	99.7	110.9	107.6
	104.4	108.5	105.5	104.2	96.1	104.6		111.6
	103.2	107.0	107.1	110.0	100.8	100.6		112.6
	97.3	109.3	109.3	104.1	100.4	97.5		110.6
	103.6	109.8	114.9	106.1	102.9	99.3		110.6
	108.7	108.5	113.3	106.3	105.7	107.3		113.6
	100.8	111.6	108.6	109.2	110.6	107.9		113.6
	101.1	108.2	107.3	109.5	110.6	101.3		107.1
	98.9	114.3	110.3	103.7	104.9	106.6		113.1
		115.9	113.9	106.8	106.6	102.1		115.1
		107.1		108.7	103.3	106.8		117.1
		97.7		109.3	107.0	105.3		110.1
		99.3		105.4	103.2	105.9		114.1
		110.7		110.6	100.0	106.2		116.1
		114.2		103.1	98.3	107.6		110.1
		106.6		109.1	98.0	110.9		110.1
		112.4			100.6	102.3		108.1
					100.9	101.0		110.1
						103.1		
Energy Average	106.5	112.1	110.8	107.2	105.6	105.2	108.0	112.9

Figure 2.3 shows the variation of horn SELs as a function of distance before and after grade crossings for the Illinois Central Railroad and the Canadian National Railroad.[19] The energy average for both railroads is also shown. The average SEL is 101.5 dBA at 1/4 mile before the grade crossing, 106.5 dBA at 1/8 mile before the crossing, and 110.5 dBA at the grade crossing.
The energy average of all studied SELs at grade crossings is 109.5 dBA from Table 2.2.

2.2.4 Summary of Measurements for Horn Noise Model Development

Information for source reference levels along the track near grade crossings was provided by previous studies. However, sufficient data to develop a propagation model was not provided. Consequently,

---

[19]   Harris Miller Miller & Hanson Inc., unpublished data, June 1998

Freight Trains at Grade Crossings
Locomotive SELs
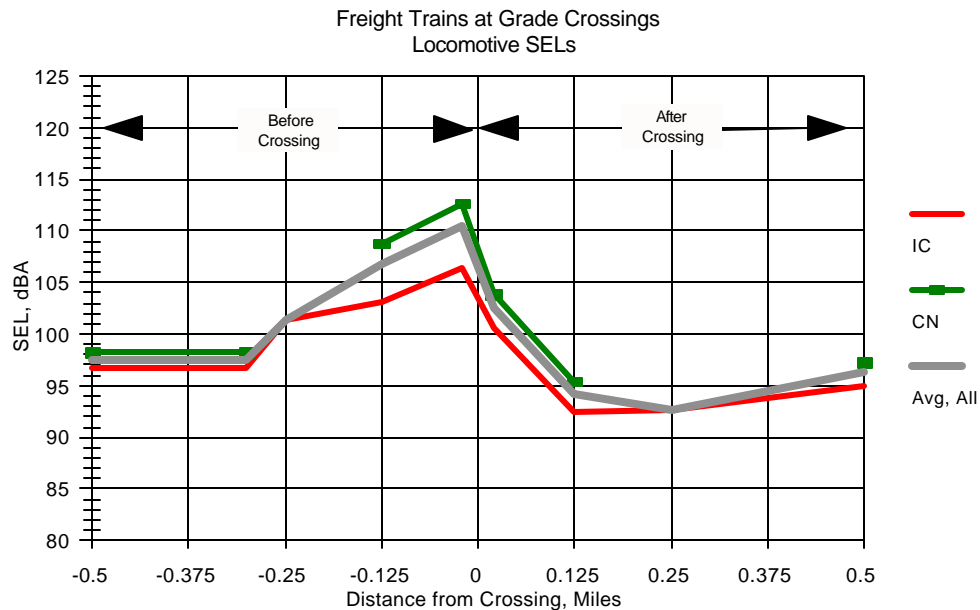
Figure 2.3. Horn SELs as a Function of Distance

additional measurements were necessary to enable a model to be developed. Sound measurements of train horns were carried out in residential areas near two at-grade crossings of main line railroad tracks in North Carolina between July 22-24, 1998. Trains using these tracks were operated by Norfolk Southern, CSX, and Amtrak.   The measurements were performed by HMMH to obtain representative field data of train horn sound needed to develop the noise model. Measurement locations, procedures, equipment, and data are in Appendix A.

Measurement locations were selected primarily to validate a propagation model (the way horn sound propagates into the community away from the tracks), and secondarily to observe the horn sounding sequences at two different crossings.   The two sites differed in the distribution of buildings near the crossings; one was in a suburban residential area near Charlotte, and the other was in a rural residential area near Fayetteville. The primary results of the measurements in North Carolina are used to confirm the validity of the propagation model before being used in a nationwide estimate of noise exposure due to horns.

The secondary result of the program was to observe horn sounding practices in the field. The results, as in previous field observations, show that there is a wide variation in how different engineers sound the horn approaching a crossing. These results are discussed in Section 3.1.3.

3. ELEMENTS OF HORN NOISE ANALYSIS

Noise generated by ground transportation is commonly analyzed in terms of a conceptual framework of source - path - receiver (Figure 4-5). A noise generating transportation **source** creates sound that propagates along a **path** to a **receiver**. Sound levels from the source are reduced (attenuated) by distance, intervening obstacle, and other factors. Finally, the receiver (the noise-sensitive land use exposed to sound from the source) perceives the sound in the context of all other sounds understood as a background sound level. The degree of impact a particular noise event causes, depends principally upon the sensitivity of the receiver and the relative increase in cumulative noise exposure (event + background vs. background). All three elements of the noise analysis as they relate to train horns near grade crossings are described in this chapter.

3.1 Noise Source

To fully describe a noise source, like a train horn, three elements of sound characteristics must be defined: the loudness, or **sound level**; the pitch, or **frequency spectrum**; and the signaling cycle, or **time variation.** These descriptors as they relate to sounds from train horns are covered in this section.

3.1.1 Sound Levels

Sounds from train horns are intended to warn people at relatively large distances from the leading vehicle of a train so that they can bring their vehicles to a safe stop before the crossing. As a result, horn systems are very loud. Federal Railroad Administration mandates a minimum sound pressure level of 96 dBA at a distance of 100 feet in front of the locomotive, or leading car.[20] According to measurements by the Volpe Center[21] described in Section 2.2.1, both of the two locomotive horns used widely in the industry are capable of exceeding the mandated minimum by a wide margin. For example, the Nathan Airchime K-5-LA, a five-chime horn, tops out at 115 dBA at 100 feet in front of an MBTA locomotive in the Volpe tests.

It takes about a second for the sound to reach a maximum in air horns, however, so the way in which the operator blows the horn makes a difference in the maximum sound level. The Volpe Center tests showed levels lower by 2 to 4 dB for the "short" blast in the standard sequence due to the delay in building up to full volume. In contrast, a continuous sounding generally results in the maximum sound

---

[20]   49 CFR Ch. 11, 229.129(a).

[21]   Keller, A., and Rickley, E. The Safety of Highway-Railroad Grade Crossings: Study of the Acoustic Characteristics of Railroad Horn Systems. Report No. DOT/FRA/ORD-93/25, June 1993.

level delivered by any horn. The maximum level can be limited by reducing the input air pressure to the horn using a regulator. This is done by some railroads to reduce community impact.

A descriptor related to the sound level is the **directivity**, or the variation in sound level around the source. The distribution of sound around a horn depends on the orientation of the individual horns in a cluster and the position of the cluster on the locomotive. Horn clusters can be made to sound in a nearly omnidirectional pattern and other patterns can be created by pointing the horns in different directions. In recent times, some railroads have selected positions of horns on top and in the center of the locomotive with clusters having horns pointing down the tracks in both directions, resulting in nearly a uniform distribution of sound around the locomotive. Others have placed horns in unfortunate locations, such as behind an electrical cabinet, which partially shield the sound signal in the forward direction. In general, a horn cluster should ideally project forward, with levels to the side considerably lower to minimize sweeping the wayside with unwanted sound.

The source level and directivity of the source combine to produce the sound heard by persons at the wayside during the passby of a train sounding its horn. The sound will rise and fall at any one location as the train approaches and passes by.   The resulting sound exposure at a location is measured by the SEL. The sound measurements used to develop the sound source level of train horns were described in Section 2 and details are provided in Appendix C. Figure 2.1 shows how the SEL varies along the track on average, starting at one quarter mile before the crossing. The SEL starts at a low level and increases to a maximum at the crossing. The variation is a result of the signal pattern, discussed further in Section 3.1.3. A model of the source level of trains is developed by averaging all the applicable data. The model shown in Figure 4.1 has a uniform SEL of 107 dBA from the 1/4 mile point to the 1/8 mile point, after which the SEL uniformly increases to a maximum of 110 dBA at the edge of road right-of-way.

3.1.2 Frequency Spectrum

The distribution of the sound signal in its various frequencies is displayed in the form of a spectrum. The human hearing spectrum is generally expressed over a range from 20 to 20,000 Hz, with maximum sensitivity between 1000 and 5000 Hz. To warn people, the horn system must emit considerable sound energy at frequencies in which the human hearing system is most sensitive.

There are two problems related to focusing all the energy in the frequency range where humans are most sensitive: some combinations of sounds in frequencies to which we are most sensitive can be very annoying to those not requiring warning, and automobile bodies are deliberately designed to reduce exterior sounds in those frequencies.   Just as a fingernail scratching on the blackboard can be very annoying, some sounds can be extremely unpleasant if they are discordant or if they include pure tones. Although such sounds can certainly be used, there is no real advantage to using ugly sounds in warning devices as long as the sound used is audible and recognizable. Since many of the potential

receivers of audible warnings from train horns are people in their cars, it is important that the sound be able to penetrate the vehicle and be heard above the background noise within the vehicle. The Volpe Center has conducted measurements of car body insertion loss and interior noise of moving vehicles with other competing noise sources in operation (radio, air conditioning, etc.)[22] Expressed in terms of insertion loss, automobiles are very effective in keeping out sounds at frequencies above about 500 Hz, and less effective at frequencies below 500 Hz. Consequently, if a car were standing still with no interior equipment operating, the ideal warning frequencies for horns would be below 500 Hz. Unfortunately, other interior noise sources tend to make up the difference. The Volpe Center's
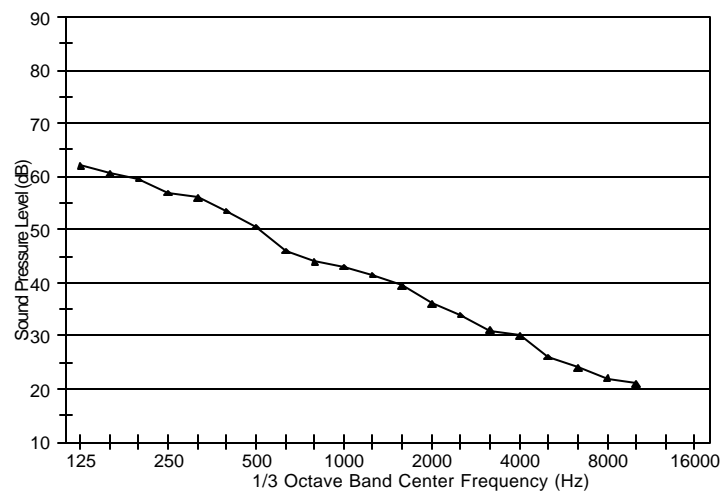
Figure 3.1. Interior Noise Environment Inside Cars
(from Rapoza, Raslear, and Rickley)

measurements of several different types of cars yielded a typical spectrum highest in the low frequencies starting at 125 Hz and falling continuously at 8 dB per octave at the higher frequencies, as shown in Figure 3.1. Unfortunately, low frequency sounds below 500 Hz also penetrate buildings quite easily. The characteristics of sound that improve warning would have the potential for increasing annoyance of people in their homes near a crossing.

To circumvent these problems, a considerable amount of research has been performed to develop horn sound combinations that have a pleasant sound, or at least not a discordant sound, with fundamental frequencies in low enough ranges to penetrate vehicles and with overtones that cover the range of human hearing sensitivity. Tests were performed with various combinations of tones to come

---

[22] Rapoza, A., Raslear, T. G., and Rickley, E., Safety of Highway-Railroad Grade Crossings: The Effectiveness of Railroad Horn Systems, Vol II. Report No. DOT/FRA/ORD XXX, August 1997.
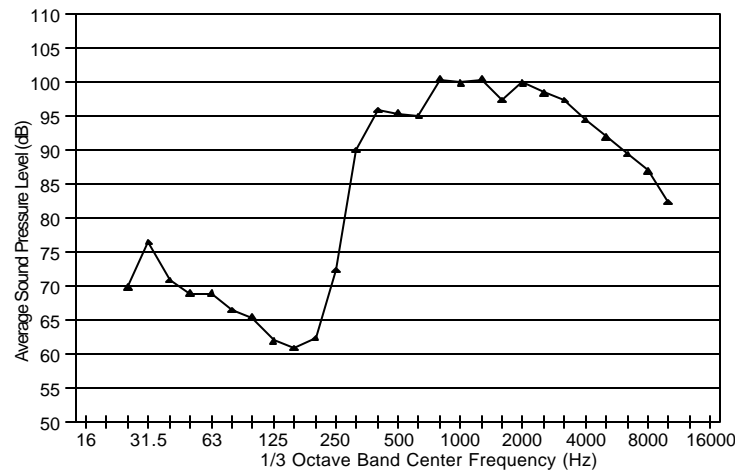
Figure 3.2. Horn Noise Spectrum- Nathan K-5-LA
(from Keller and Rickley)

up with pleasing overall effect, while still performing the warning function.[23] The fundamental frequencies of the individual horns in clusters are in the desired low frequency ranges. For example, the Nathan K-5-LA horns used on MBTA commuter trains and many Amtrak locomotives have five chimes with frequencies of 311 Hz, 370 Hz, 415 Hz, 494 Hz, and 622 Hz. However, by including all the combinations of overtones, the frequency spectrum is rich in frequencies up into the 4000 Hz range, as shown in Figure 3.2.

3.1.3 Time Variation of Signal

The time variation of a signal affects the SEL in proportion to the time that the signal is on compared to the total time of the pattern. Horns are used as warning devices at grade crossings and are supposed to be sounded in a "long-long-short-long" sequence with the last "long" blast occurring as the leading equipment traverses the grade crossing.   Measurements in the field show that there is no consistency in the way engineers actually blow their horns. However, when the standardized sequence is sounded, the durations of the "long" signals are about 5 seconds and the "short" signal is about 2 seconds.[24] When there is a defined pattern, the time of horn sound amounts to about 70% of the total time of the pattern.   The down-time between horn sounds causes a reduction in the sound energy as measured by SEL. That is one of the reasons why the SEL in Figure 2.1 is lower over the

---

[23] Robert Eugene Swanson, 1905-1994, *Horn & Whistle*, No. 66, Winter 1994-95.

[24] Keller, A., and Rickley, E. The Safety of Highway-Railroad Grade Crossings: Study of the Acoustic Characteristics of Railroad Horn Systems. Report No. DOT/FRA/ORD-93/25, June 1993.

first 1/8th mile than over the last 1/8th of a mile before a road crossing. The other reason is related to the inconsistency in the way horns are blown at crossings. The wide variety of horn sounding practices results in lower SELs further away from the crossing; some engineers do not start sounding at 1/4 mile, and some do not even start until the 1/8th mile point.   However, horn sounding consistency is much greater at the grade crossing itself and the SELs show a peak at that location. As an example of the inconsistency of horn sounding practices, some of the actual sounding sequences recorded at grade crossings in North Carolina are shown in Figure 2.2.

3.2 The Path

The second part of the noise analysis paradigm is the sound propagation path through the air between the source and the receiver. This path includes not only the direct line of sight from the horn to nearby buildings, but also several potential reflected and refracted paths over the ground, terrain features, vegetation, fences and walls, and buildings.

3.2.1 Direct Path: Geometric Spreading

Sound waves radiate in all directions from the horn cluster. The horn cluster acts as a point source in this case, as opposed to the line source represented by the train. A stationary point source sends sound energy radially in all directions, thereby resulting in a spherical spreading of the sound energy. Mathematically, this is a $1/R^2$ type of spreading, where R is the radial distance traveled by the sound, similar to the so-called "inverse square law" in the radiation of light waves from a light bulb. In acoustics, the inverse square law results in a 20 log R reduction in sound level, which amounts to a 6 dB reduction for every distance doubling in ideal free-field conditions.

Environmental assessments use the day-night sound level (L_{dn}) as the metric for noise impact. This descriptor is based on the sound energy emitted from all the events during a full 24 hours. The basic unit for computing the L_{dn} is the Sound Exposure Level (SEL), which represents the total sound energy at a receiver from one event normalized to a one-second duration. Sound energy from a moving point source, like a horn on a passing train, is accumulated at the receiver. Mathematically, the SEL is the result of integrating the sound energy from the passby. It can be demonstrated that the geometric spreading associated with SEL from a moving point source is more like a cylinder, expressed as 1/R. In acoustics, the cylindrical spreading results in a 10 log R reduction in sound level, or a 3 dB reduction for every distance doubling in free field conditions. This geometric spreading relationship is used in the model.

3.2.2 Direct Path: Atmospheric Conditions

Sound waves propagate through the air as a medium, with the sound energy passed along by the motion of air molecules. Air molecules move faster when they heat up so sound waves move faster in warmer air than in colder air. As a result, temperature gradients in the air have a large effect on sound propagation, causing sound waves to bend upwards over warm ground in bright sunlight and thereby reducing sound transmission to nearby receivers on the ground. The opposite effect occurs during evening hours when the ground cools off, or for transmission over a body of water, when the sound waves bend down toward receivers on the ground. Moreover, since the air is nearly constantly in motion, sound waves are continuously subject to the effects of the wind and wind gradients. These weather conditions change on a daily, and even hourly, basis and tend to average out over a period of a year. Consequently, the horn noise model, like most noise models, ignores weather effects and assumes ideal conditions.

3.2.3 Reflected Path: Ground Effects

Hard and soft ground. Sound waves radiate in all directions from a horn cluster, and much of that sound energy reflects off the ground between source and receiver. The details of the ground surface make a big difference in what happens to the reflected waves. If the ground is flat and hard like a parking lot or a wide road, the waves reflect smoothly and combine with those in the direct path such that they add to the sound energy transmission. On the other hand, if the ground is soft and absorbent like a grassy field, the reflection is reduced. The latter condition describes most of the ground in the vicinity of railroad tracks. Field measurements tend to confirm a 25 log R relationship, or 7.5 dB reduction for every distance doubling from a point source like a train horn cluster. The corresponding effect on the propagation of SEL is a 15 log R relationship, or a 4.5 dB reduction for distance doubling.

Vegetation. Trees, shrubs, and vegetation have surprisingly little effect on the propagation of sound. The main effect is to scatter sound in many directions without much attenuation. Noise prediction models do allow some sound reduction for dense vegetation; FRA's noise prediction method gives between 5 dB and 10 dB reduction for sound propagation through a dense forest, but to attain this it must have more than 100 feet of dense, high vegetation between source and receiver.[25] A single row of shrubbery along the right-of-way line will be ineffective in noise reduction. Therefore, the effect of vegetation is ignored in the horn noise model.

---

[25] U.S. Department of Transportation, Federal Railroad Administration. "High Speed Ground Transportation Noise and Vibration Impact Assessment," Final Draft Report, December 1998.

3.2.4 Refracted Path: Shielding

Rows of buildings and other barriers act to interfere with sound taking a direct path to the receiver. Besides the shielding afforded by rows of buildings in urban and suburban areas, other blockage results from man-made sound walls and natural terrain features such as hills and earth berms. When sound waves encounter a barrier in the direct path between a source and a receiver, they reflect off in another direction. Only the sound energy going over the top or around the sides of the barrier can reach the receiver. The mechanism is refraction, or bending of the sound waves, which reduces the amount of sound energy that reaches any given point in the shadow zone on the other side of the barrier. The greater the refraction angle, the greater the sound reduction.

Since most existing whistle bans are located in urban and suburban areas where rows of homes and other buildings are common, a generalized effect of noise reduction from shielding is assumed in the horn noise model. In the FRA noise prediction method,[25] shielding from buildings depends on the number of rows of buildings and the percentage of open gap between buildings compared to the length of the row. Not every grade crossing situation is accompanied by neat parallel streets and orderly rows of buildings. However, a reasonable assumption for a national average, based on observations of urban and suburban grade crossings, is that the first row of buildings occurs at 200 feet from the tracks, with succeeding rows of buildings at 200 foot intervals, with gaps between buildings constituting between 35 and 65 percent of the length of the row. This layout is not referenced to any particular place in the United States, but rather represents a composite average effect of typical orientation of homes and structures near grade crossings where a whistle ban is in effect. Given this assumption, the FRA noise prediction method attributes a 3 dB reduction at the first row of buildings at 200 feet from the tracks, and a 1.5 dB reduction for each succeeding row at 400, 600, 800, and 1000 feet.

3.3 The Receiver

The third part of the noise analysis is the receiver of noise. In the case of horn noise impact, the noise-sensitive receivers are considered to be people and their homes. Criteria for noise impact for various land use categories have been established by FRA and other Federal agencies, largely based on research conducted by the U.S. Environmental Protection Agency in the 1970's. These criteria are discussed below.

3.3.1 Receiver Response to Transportation Noise

Noise can interrupt ongoing activities and can result in community annoyance, especially in residential areas. In general, most residents become highly annoyed when sound interferes significantly with activities such as sleeping, talking, noise-sensitive work, and listening to radio, TV, or music. In

addition, some land uses, such as outdoor concert pavilions, are inherently incompatible with high noise levels.

Annoyance to noise has been investigated and approximate exposure-response relationships have been quantified by the Environmental Protection Agency (EPA).[26,27] The selection of noise descriptors in this manual is largely based upon this EPA work. Beginning in the 1970s, EPA undertook a number of research and synthesis studies relating to community noise of all types. Results of these studies have been widely published. Basic conclusions of these studies have been adopted by the Federal Interagency Committee on Noise [28], the Department of Housing and Urban Development (HUD)[29], the American National Standards Institute [30], and even internationally.[31] Conclusions from this seminal EPA work remain scientifically valid to this day.

In a large number of community attitudinal surveys, transportation noise has been ranked among the most significant causes of community dissatisfaction. A synthesis of many such surveys on annoyance appears in Figure 3.3.[32,33] Different neighborhood noise exposures are plotted horizontally. The percentage of people who are *highly annoyed* by their particular level of neighborhood noise is plotted vertically. As shown in the figure, the percentage of high annoyance is approximately 0 percent at 45 decibels, 10 percent around 60 decibels and increases quite rapidly to approximately

---

[26] Environmental Protection Agency, "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure," Task group 3, Henning von Gierke, Chairman, Report NTID 73.4, Washington DC, 27 July 1973.

[27] Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," Report No. 550/9-74-004, Washington DC, March 1974.

[28] Federal Interagency Committee on Urban Noise, "Guidelines for Considering Noise in Land Use Planning and Control," a joint publication of the Environmental Protection Agency, the Department of Transportation, the Department of Housing and Urban Development, the Department of Defense, and the Veterans Administration, Washington DC, June 1980.

[29] Department of Housing and Urban Development, "Environmental Criteria and Standards of the Department of Housing and Urban Development," 24 Code of Federal Regulations Part 51; 44 Federal Register 40861, Washington DC, 12 July 1979.

[30] American National Standards Institute, "American National Standard: Compatible Land Use With Respect to Noise," Standard S3.23-1980, New York NY, May 1980.

[31] International Standards Organization, "Assessment of Noise with Respect to Community Response," Recommendation R-1996, Geneva, 1971.

[32] T.J. Schultz, "Noise Rating Criteria for Elevated Rapid Transit Structures," U.S. Department of Transportation Report No. UMTA-MA-06-0099-79-3, Washington DC, May 1979.

[33] T. J. Schultz, "Synthesis of Social Surveys on Noise Annoyance," Journal of the Acoustical Society of America, Vol. 63, No. 8, August 1978.

70 percent around 85 decibels. The scatter about the synthesis line is due to variation from community to community and to some wording differences in the various surveys. A recent update of the original research, containing several additional railroad, transit and street traffic noise surveys, confirmed the shape of the original Schultz curve.[34]
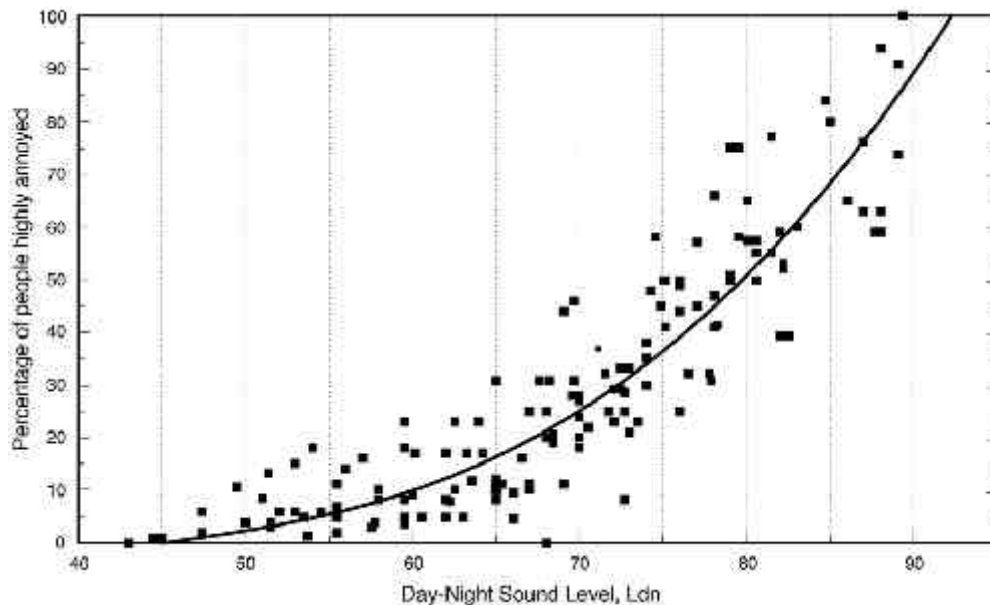
Figure 3.3. Noise Annoyance Curve (source: *T. J. Schultz, "Synthesis of Social Surveys on Noise Annoyance," Journal of the Acoustical Society of America, Vol. 63, No. 8, August 1978*).

Introduction of horn noise may have two undesirable effects. First, it may significantly increase existing noise levels in the community, beyond levels residents have become accustomed to. This effect is called "relative" noise impact. Evaluation of this effect is "relative" to existing noise levels; relative criteria are based upon noise increases above existing levels. Second, newly-introduced noise may interfere with community activities, independent of existing noise levels; it may be simply too loud to converse or to sleep. This effect is called "absolute" noise impact, because it is expressed as a fixed level not to be exceeded and is independent of existing noise levels. Both of these effects, relative and absolute, enter into the assessment of noise impact. These two types of impact, relative and absolute, are merged into the noise criteria shown in Figure 3.4. A full description of the derivation of the criteria is given in the new FRA noise impact assessment manual.[35] These criteria are

---

[34] S. Fidell, D.S. Barber, and T.J. Schultz, "Updating a Dosage-Effect Relationship for the Prevalence of Annoyance Due to General Transportation Noise," Journal of the Acoustical Society of America, Vol. 89, No. 1, January 1991.

[35] U.S. Department of Transportation, Federal Railroad Administration. "High Speed Ground Transportation Noise and Vibration Impact Assessment," Final Draft Report, December 1998.

used in this report for residential land use and places where people normally sleep, like hotels and hospitals. L_{dn} is the noise descriptor for assessment of noise impact for residential areas.
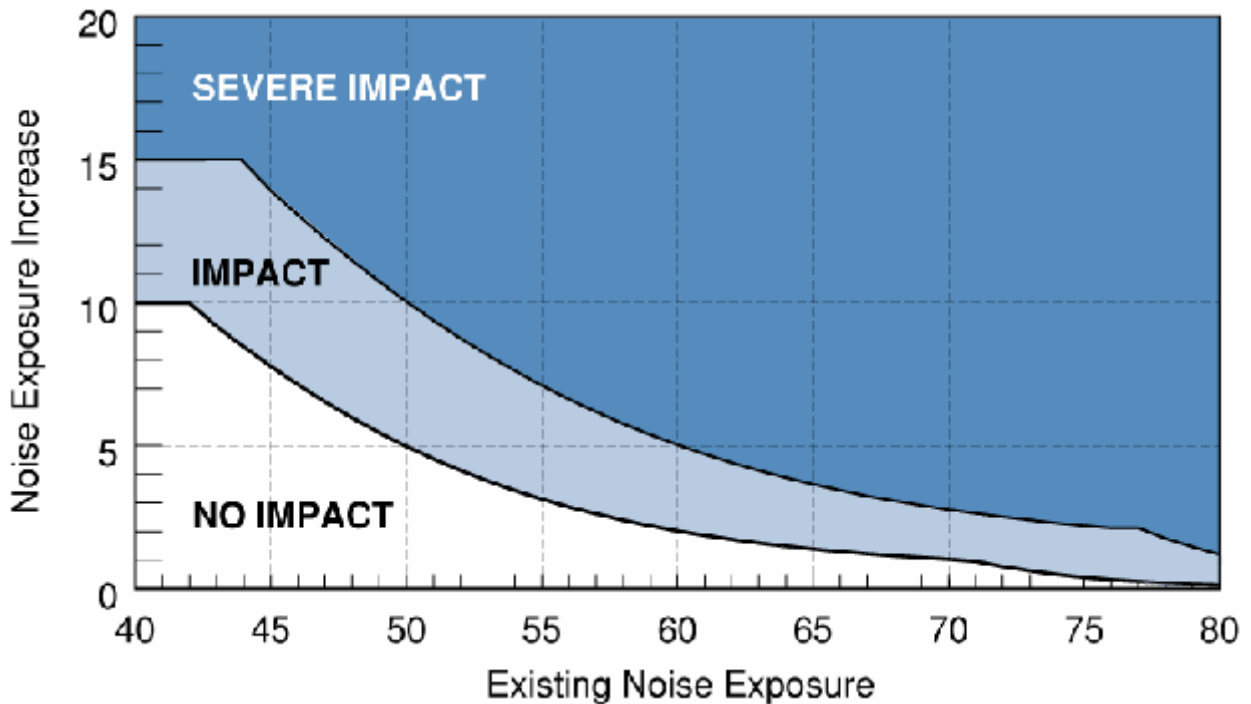
Figure 3.4. Noise Impact Criteria for Residential Areas Using L_{dn}

4. HORN NOISE MODEL DEVELOPMENT

The horn noise model used in the assessment of impacts related to the proposed Use of Locomotive Horns rule is based on methods and approaches used and approved by Federal agencies for environmental assessments of transportation projects nationwide (described in Chapter 3). The model includes source, path, and receiver elements specifically selected from the information presented in Section 3 of this report. The model has been customized to a limited extent, in that data are utilized from the FRA grade crossing inventory that affect the noise source level at each grade crossing. Information input into the model includes: traffic volumes of trains and motor vehicles, speed of trains, and estimated background noise levels. The background noise level chosen for this analysis is discussed in Section 4.3 of this report. Grade crossing features left unspecified are the terrain and building locations that affect the propagation path.

The noise model has been applied to every grade crossing under study to estimate areas of potential impact and severe impact according to the FRA noise criteria, shown in Figure 3.4. The program calculates the vertices of an actual polygon containing the impact areas for each crossing. The

population impacted by horn noise is estimated by the proportionate number of people included within the impact polygons according to census block data for each location near a grade crossing. Further details on each element of the noise model follow.

4.1 Source Levels

Reference Level. Although the maximum sound output of a horn can be determined in a laboratory, it is the horn's use in the real world that determines its effect on the environment. The standard horn sounding sequence for grade crossing warnings was discussed in Section 2.2.2 however, there are a wide variety of actual sounding practices. Development of a source reference level to use in the horn noise model was based on field measurements at grade crossings in numerous states. Although not all engineers commence sounding horns at 1/4 mile in advance of a grade crossing, that point was selected as the average start of the sounding sequence based on recent measurement observations while performing measurements, and the requirement in the proposed rule that the horn sounding sequence start at that point.

Rather than a single reference level, a reference level that varies along the tracks beginning 1/4 mile in advance of the crossing and ending at the crossing was found to be more accurate. The reference level is shown in Figure 4.1. Recent data show an average reference SEL of 107 dBA at 100 feet from the nearest track represents the horn noise in the stretch from 1/4 mile to 1/8 mile in advance of a crossing. Starting at the 1/8 mile point, the data show the horn is sounded more continuously in the last part of the sounding sequence as the train approaches the crossing. Consequently, the SEL is assumed to increase linearly to 110 dBA at the roadway right-of-way line. These assumptions result in the five-sided polygon shown shaded in Figure 4.1. This figure is the basis for the horn noise model
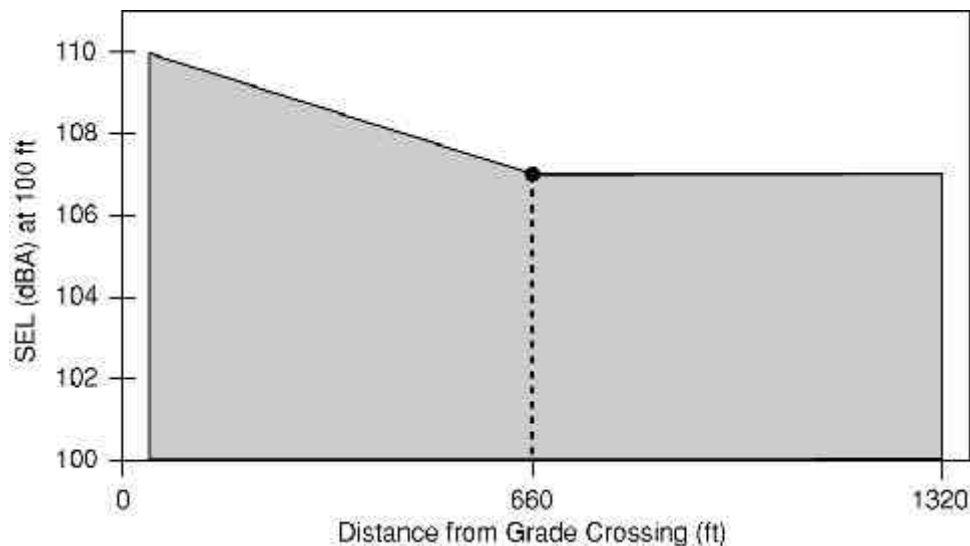
Figure 4.1. Source Level Model

and the impact and severe impact areas at each grade crossing.

Day-Night Sound Levels. The reference SEL and the number of train passbys during day and night are used as the basis for calculating the L_{dn} for use in the FRA noise impact criteria, as described in Chapter 3. The equations in the FRA guidance manual take the calculation process through the hourly L_{eq}, which is important for assessing noise impacts for systems that strictly adhere to schedules. However, freight operations occur on schedules that may vary by many hours from one day to the next. As a result, the daytime hours from 7 a.m. to 10 p.m. and nighttime hours from 10 p.m. to 7 a.m. the next morning are the most finely tuned time periods we can obtain for the calculation of L_{dn}. Since the FRA grade crossing inventory assumes that the daytime hours are from 7:00 a.m. to 7:00 p.m. and the nighttime hours are from 7 p.m. to 7 a.m., a small adjustment was made in calculating the L_{dn} for the grade crossings under study. Consequently, the calculation of L_{dn} proceeds as follows:

$$L_{eq}(\text{day}) = SEL_{Ref} + 10 \log (V_{day}) - 35.6,$$

$$L_{eq}(\text{night}) = SEL_{Ref} + 10 \log (V_{night}) - 35.6,$$

$$L_{dn} = 10 \log \left[15 \cdot 10^{L_{eq}(day)/10} + 9 \cdot 10^{(L_{eq}(night)+ 10)/10} \right] - 13.8$$

where V_{day} = average hourly daytime volume of train traffic, and
V_{night} = average hourly nighttime volume of train traffic.

4.2 Propagation

Sound propagation depends on a great number of factors, which were discussed in much greater detail in Section 3.2. The key effects of geometric spreading (divergence), ground effects, atmospheric effects, and shielding are built into the horn noise model as described in the following subsections. The assumed propagation effects are shown in Figure 4.2. Each of the following effects are important in determining the distance to impact and "severe impact," which in turn determine the size of the impact polygons.

Divergence. The sound from a horn is assumed to act as if it were emitting from a moving point source, which when averaged over the length of track acts like a line source with a 3 dB reduction for every distance doubling.

Ground effect. The model takes into account a generalized soft ground condition, assuming that most grade crossings with whistle bans are located in residential areas with grass and vegetation. This assumption results in an additional 1.5 dB reduction per distance doubling, so that when combined with the divergence relationship, a total of a 4.5 dB reduction per distance doubling applies.

Atmospheric effects. The model does not take into account atmospheric effects, assuming that if averaged over an entire year, the average condition is a uniform, quiescent atmosphere.

Shielding. The model also takes into account shielding from rows of buildings. As described in Chapter 3, a general model for a national average of shielding at grade crossings in the FRA inventory was assumed. The general model was based on observations of urban and suburban grade crossings combined with field verification of the FRA noise prediction method with shielding (See Appendix A). The generalized finding is that the first row of buildings occurs at 200 feet from the tracks, with succeeding rows of buildings at 200 foot intervals, with gaps between buildings constituting between 35 and 65 percent of the length of the row. Given this assumption, the model attributes a 3 dB reduction at the first row of buildings at 200 feet from the tracks, and a 1.5 dB reduction for each succeeding row of buildings at 400, 600, 800, and 1000 feet.
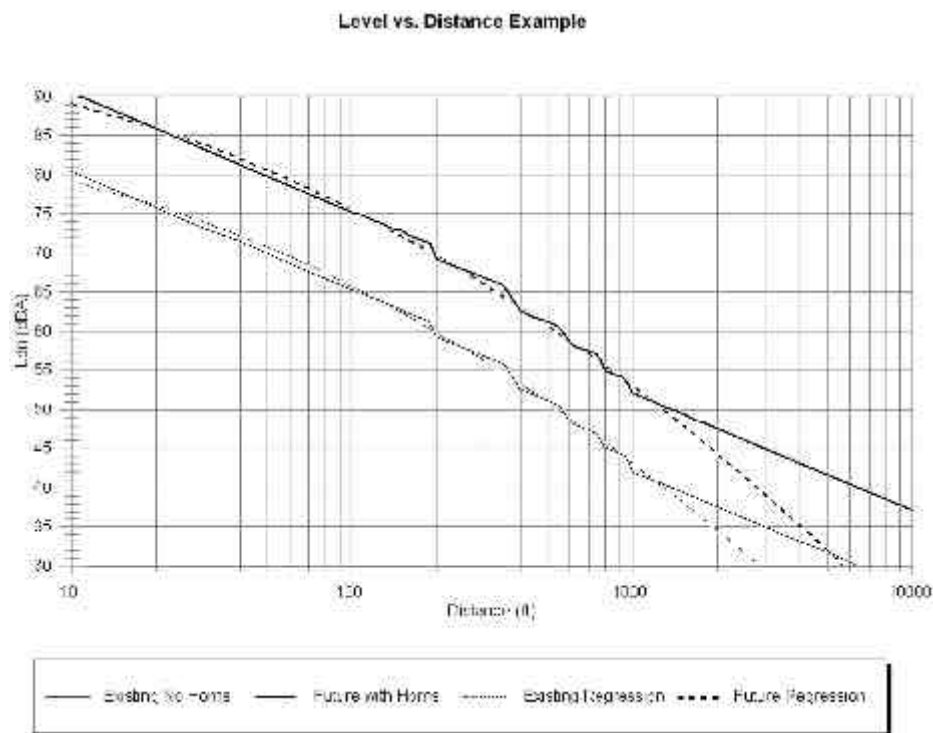
Figure 4.2. Assumed Sound Propagation from Horns

4.3 Impact Zones

Noise impact criteria used by the FRA are based on noise exposure increase. The existing noise in the immediate vicinity of the tracks is assumed to be dominated by trains. The train noise L_{dn} depends on the number of trains passing during the day and night, as discussed in Section 3.3, with noise reduction with distance as discussed in Section 4.2. At some distance from the track, however, a general ambient noise level is attained that is characteristic of the general ambient environment away from the influence of railroad noise. According to the U.S. Environmental Protection Agency, the

typical ambient level in a suburban residential area is $L_{dn} = 55$ dBA.[36] This level represents the noise "floor" in the noise impact calculation method.

The horn noise model computes the horn noise in terms of Ldn as a function of distance from the tracks, and the train noise without horns as a function of distance from the track down to a noise floor established by the ambient noise. These curves are shown in Figure 5.1. The two curves are compared at each distance until the noise impact criteria ratings of impact and severe impact are reached for land use Category 2, residential land use. Since the original source model, shown shaded in Figure 4.1, is a polygon with 5 sides, the impact areas will be similar polygons.

4.4 Typical Polygon Template

Typical impact and severe impact polygon templates are shown in Figure 4.3. The entire impact area is made up of two sets of four identical polygons at each grade crossing, each set representing either the impact or severe impact areas. Each of the polygons are mirror images reflected around the axis represented by the road and the axis represented by the tracks. Consequently, the horn noise model can be exercised one time at each grade crossing to calculate the vertices of the impact polygon in one quadrant. The other three quadrants are determined by symmetry. The details of the impact polygons and the calculations of the vertices are given in Chapter 5.
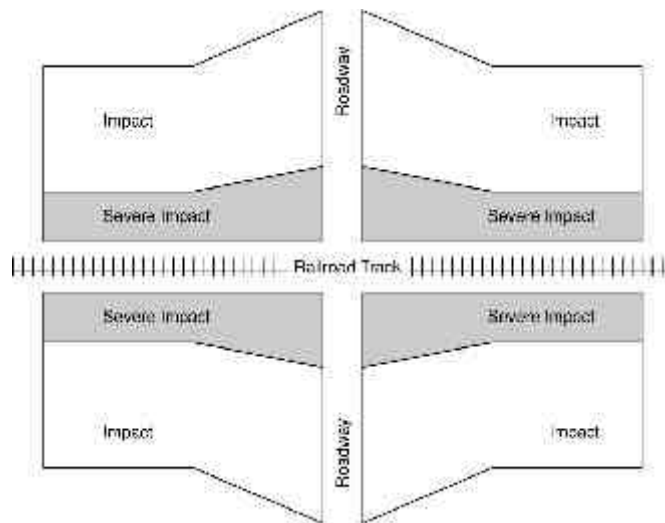
Figure 4.3. Typical Impact Polygons

---

[36] U.S. Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. EPA Report No. 550/9-74-004, March 1974.

5. IMPLEMENTATION OF THE MODEL

The horn noise model and other computer manipulation discussed in this section was designed to interact with the FRA inventory containing information about each of the grade crossings under study. A C++ computer program is the basis of the primary horn noise model. Supplemental spreadsheet programs and have been developed to convert primary horn noise functions to impact polygons with x-y coordinates and finally to spatially located impact zones for use in GIS. Finally, a GIS system was used to estimate population exposure to horn noise.

5.1 The Horn Noise Computer Model

The horn noise computer model is used to develop the impact and severe impact distances for each of the grade crossings. The calculation of these distances involves complex functions of noise level versus distance, and is much easier to model with a computer program. Each of the steps taken in the computer program and the input and output of the program are detailed in the following section.

5.1.1 Information from the FRA Grade Crossing Inventory

Each grade crossing is identified with an alpha-numeric code unique to the grade crossing. The FRA grade crossing inventory contains a large amount of information related to each grade crossing. The inventory contains information on the railroad using the tracks, the type of signaling at the crossing, the location, and a host of other fields of information. The first task in setting up the program was determining the pertinent information for the horn noise model and extracting it from the FRA grade crossing inventory for use in the computer program. The program selects the following specific data fields: train traffic in terms of daytime and nighttime split; speed; number of tracks; number of roadway lanes, and the latitude and longitude of the center point of the grade crossing. This unique information is combined with generalized information used for every crossing.

5.1.2 Input to the Computer Program

The first two variable inputs into the computer program are the reference SELs for both the trains without horns and with the horns. These two inputs default to the levels discussed below, but are left as variables to determine the effects of changes in the noise levels of the trains and their horns. In addition, the reference SEL for the trains without the horns can be varied according to speed. The speed taken from the FRA grade crossing inventory is used in calculating the reference noise levels from the existing trains.

The next set of inputs are the assumed background Ldn and the propagation characteristics due to residences and terrain at the grade crossings. The background Ldn is set at 55 dBA, the standard

suburban Ldn as discussed in Section 4.3. Propagation characteristics, such as distances to rows of houses and the amount of shielding attributed to each row, are inputs into the program. The default values are rows at 200 feet, 400 feet, 600 feet, 800 feet and 1000 feet. The first row of houses has 3 dB of shielding and each successive row has an additional 1.5 dB of shielding.

5.1.3 Calculation of Existing Noise Levels

Calculation of the existing noise is the first step in determining the amount of impact from horn sounding at a grade crossing with a current whistle ban. Since the FRA noise impact criteria are based on existing noise levels, they are an important part of the model. The existing noise levels in the vicinity of the grade crossing are calculated at 100 feet from the tracks using a reference SEL from a single train. The reference SEL obtained from measurement data is 100 dBA at 40 mph.   This reference SEL is adjusted for the speed at the crossing (unless the default speed of 40 mph is assumed) and the number of trains using the grade crossing in a single day. Both of these adjustments are taken from the FRA grade crossing inventory. The relationships for each are:

Speed: $10 \log (S/40)$,
where S = the speed at the grade crossing

Number of trains: $10 \log (N)$,
where N = number of trains.

Horns are not assumed to be blown under existing conditions, so the SEL is due to the noise generated by the trains only (locomotives and cars). The equations for calculating L_{dn} from the reference SEL are given in Section 3, where first the L_{eq} (day) and L_{eq} (night) are calculated and then combined to develop the day-night descriptor (L_{dn}). Since the definitions of "daytime" and "nighttime" periods in the noise model do not coincide with those in the inventory, the FRA grade crossing inventory values are adjusted to reflect the day and nighttime periods as defined in the calculation of L_{dn}. The adjustments result in a reference L_{dn} at 100 feet, used to calculate the noise level as a function of distance at each grade crossing with the propagation model described in Section 4. The noise levels from the trains decrease as a function of distance until the train noise is equal to the background L_{dn} (55 dBA in the default setting), at which point the existing noise is assumed to be uniform and the train makes no more contribution to noise levels.

5.1.4 Calculation of Horn Noise Levels

Noise levels from horn sounding are calculated similarly to the procedure described above, with some exceptions. The first exception is that the horn noise is not dependent on speed. The next exception is that instead of one reference level, two reference levels are used, as shown in Figure 4.1. The two reference SELs are 110 dBA and 107 dBA. The numbers of day trains and night trains are used to

calculate L_{dn}. The noise levels from the horns decrease as a function of distance until the horn noise is equal to the background L_{dn} (55 dBA in the default setting), at which point the existing noise is assumed to be uniform and any further effect of the train horn is negligible.

5.1.5 Calculation of Distance to Impact and Severe Impact

Determination of the distances to impact and "severe impact," as defined by the FRA noise impact criteria described in Chapter 3, are the final calculations carried out by the computer program. Existing noise levels are applied to FRA's noise impact criteria (Figure 3.4) to arrive at two curves of impact and severe impact level versus distance. The two points at which these curves intersect the curve of horn noise versus distance are the threshold distances for severe impact and impact. Two sets of these points are generated by the computer program. The first set is for the train horn SEL of 110 dBA (at the grade crossing) and the second set is for the train horn SEL of 107 dBA (for distances greater than 1/8 mile from the grade crossing). Example curves are shown in Figure 5.1.
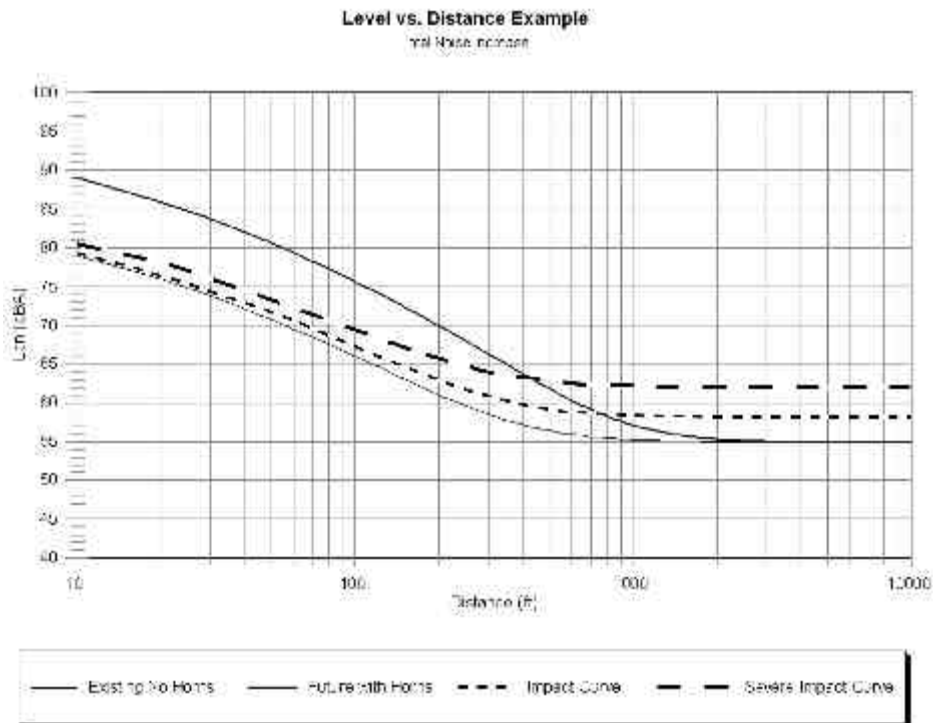
Figure 5.1. Determination of Impact Distances

5.1.6 Output from the Horn Noise Computer Model

After completing all the above calculations for each of the grade crossings under study, the computer program generates an output file that can be used in a spreadsheet model to determine the impact polygons. The output is a text file and has the following fields for each grade crossing:

1.   Crossing ID - The program takes the Crossing ID from the FRA grade crossing inventory and keeps it with the crossing data.

2.   Longitude and Latitude - The longitude and latitude of the center point of the crossing are taken from the FRA grade crossing inventory to be used in the calculation of the vertices of the impact polygons.

3.   Impact Distances - The four impact distances calculated in Section 5.1.5 are output as columns in the text file. The distances to impact and severe impact for both the area near the grade crossing and the area more than 1/8 mile from the grade crossing are included in the file.

4.   Other Information - In addition to the above information, the train speed, the number of equivalent trains, and the reference L_{dn}s for both the trains with and without horns are included for each grade crossing. This information is included for reference only, and is not used in the calculations of the impact polygons.

5.2 Supplemental Computer Modeling

With modeling of locomotive horn noise at each grade crossing completed, the effort turned to applying the model results to the crossings under study to estimate noise impacts. A GIS program (ArcInfo) was used to overlay census block data with the noise impact polygons to estimate the number of people impacted and severely impacted at every grade crossing studied.

To facilitate the transfer of data from the horn noise model to ArcInfo, a computer spreadsheet model was developed to calculate the overlapping impact polygons at each grade crossing. The spreadsheet calculated a series of five X-Y coordinates for each polygon (both impact and severe impact) in each of the four quadrants of the grade crossing. This representation of the impact polygons was then refined so that the polygons were in a form that ArcInfo could use.

5.2.1 Development of the Noise Impact Polygons

The horn noise impact polygons described in Section 4 take the shape shown in Figure 5.2. The polygons have five sides and five vertices in each quadrant of the track/road intersection.
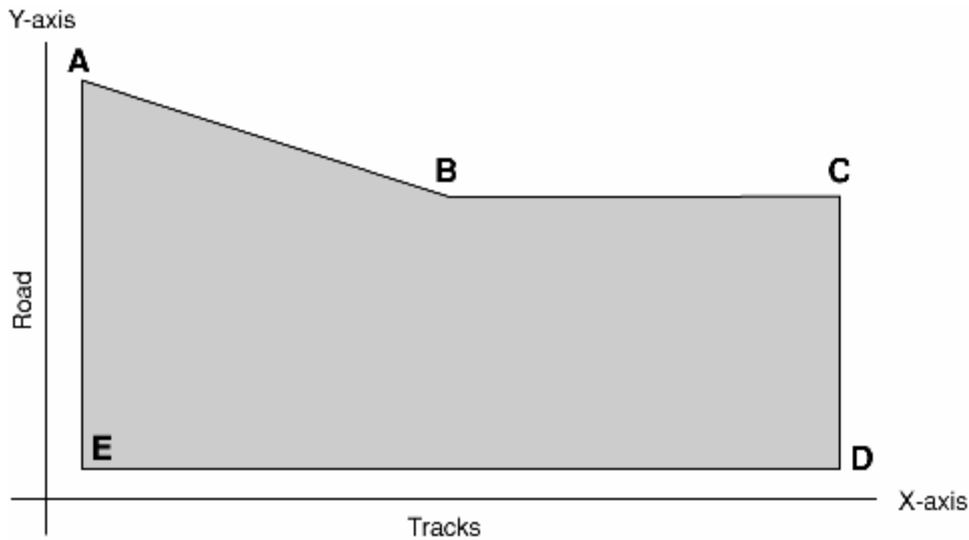
Figure 5.2. Impact Polygon Shape

The five vertices of a polygon are determined in Cartesian coordinates (X-Y), where the origin (or 0,0 point) of the X-Y plot is the grade crossing itself, the X-axis is assumed to fall on the tracks, and the Y-axis is perpendicular to the tracks along the roadway. The spreadsheet takes into account the width of the road and the railroad tracks in calculating the impact polygons.

The spreadsheet uses the number of tracks and the number of roadway lanes at each grade crossing. This information is taken from the FRA grade crossing inventory. This information is used to calculate the width of the tracks and roadway using the following relationships:

Width of Roadway = ((No. Lanes x 12 ft) + 20 ft) or 40 ft, whichever is larger.

Width of Rail Right of Way = ((No. Tracks x 14 ft) +20 ft) or 50 ft, whichever is larger.

With this information and the impact and severe impact distances at the grade crossing and at 1/8 mile from the grade crossing, the vertices of the impact polygons are calculated. For each vertex, labeled A, B, C, D and E in Figure 5.2, the X-Y coordinates for the impact polygon are determined as shown in Table 5.1. A separate polygon is determined for severe impact in a similar manner. The polygons in the other three quadrants of the X-Y coordinate system are calculated by symmetry.

The FRA crossing locations were originally given in decimal degrees. To allow the measurements to be calculated in feet, the data sets were converted into UTM (Universal Transverse Mercator) coordinates. Within the GIS application, ArcInfo, point coverages were generated for all crossings. The point coverages were projected into the same UTM coordinate regions used with the original data sets.

Table 5.1. Development of Noise Impact Polygons

Vertex	X-Coordinate	Y-Coordinate
A	Half the width of the roadway	Calculated distance to impact at the grade crossing
B	1/8 mile from roadway centerline (660 feet)	Calculated distance to impact at 1/8 mile
C	1/4 mile from roadway centerline (1320 feet)	Calculated distance to impact at 1/4 mile (same as 1/8 mile)
D	1/4 mile from roadway centerline (1320 feet)	Half the width of the rail right of way
E	Half the width of the road	Half the width of the rail right of way

In order to determine the proper angle of the noise polygons, the angle of railroad tracks at each crossing had to be identified. To accomplish this, the polar angle of the railroad at each crossing was obtained by creating a macro within the ArcInfo GIS program. The macro created a circular buffer around each crossing point and then selected the portion of the railroad track that passed through the buffer. The polar angle of the approximately 1000-foot railroad line was then calculated from the angle of intersection of the rail segment and the buffer. The spreadsheet model was then able to apply the correct orientation of each grade crossing under study to the noise impact polygons.

Two text files were created from the spreadsheet with the coordinate values for the noise polygons. These two files corresponded to the two separate noise polygons types: impacted population noise polygons; and severely impacted population noise polygons.

The text files were formatted as ArcInfo "polygon generate" files in order for ArcInfo to create GIS data sets from them. Two ArcInfo polygon coverages, one for each noise polygon type, were then generated from the formatted text files.

5.2.2 Estimation of Population Noise Exposure

To estimate the impacted population and severely impacted population for grade crossing, a GIS overlay process was performed with the noise polygon coverages and with 1990 census block polygon coverages. This process resulted in individual noise polygons associated with grade crossings and with assigned census data.

Because the noise impact polygons for different grade crossings can overlap one another, and a census block polygon can be split by many overlapping noise polygons, a method had to be developed to avoid double counting impacted populations. To avoid double-counting populations, census block population totals were calculated for the portions of census block polygons that occurred from census blocks split by multiple noise polygons using the following formula:

$$P = PA * T / N$$

Where,

P = Population of Census Block Portion
PA = Area of Census Block Portion / Area of Census Block,
T = Total Census Block Population
N = Number of times Census Block Portion is intersected by a Noise Polygon

For example, the population for a census block portion with an area of 12,000 square feet that fell within 3 noise polygons, and was part of a census block with a population of 100 and an area of 24,000 square feet would be calculated as follows:

$$P = (12,000/24,000) * (100/3)$$

Once this formula was applied to every split census block, impacted populations were totaled within ArcInfo by spatially selecting the split census blocks that fell within a noise impact polygon and summing those population values.

For the environmental justice analysis, the resulting data from the above process was exported into a Microsoft Access database. In Access, minority population and low-income data were added to the resulting noise impact data to determine whether these variables are in proportion to the population percentages of minority and low-income residents for the county that grade crossing is located.

Summary tables describing the results of the population and environmental justice analyses were created and are included in the Use of Locomotive Horns DEIS.

5.2.3 Estimation of National Population Noise Exposure Reduction

Several provisions of the proposed rule would affect locomotive horns, the sound they make, and how they would be used when approaching an at-grade crossing. The models developed for the above impact analysis were used to analyze these additional provisions which may lead to a reduction of community noise attributable to train horns.

Horn Sounding Sequence The horn noise impact assessment assumed a uniform 1/4 mile distance for the horn sounding at all the grade crossings. All impact polygons extended for 1/4 mile each side of the grade crossing. However, the proposed rule contains provisions that direct railroads to locate whistle posts or boards such that engineers would be directed to sound the horns for a period of 20 seconds (based on maximum track speed), up to a maximum distance of 1/4 mile from the grade crossing. This means all impact polygons associated with speeds less than 45 mph, the time it takes to travel 1/4 mile in 20 seconds, will actually be shorter than 1/4 mile.

In order to model a combination of time and distance instead of only distance, the maximum timetable speed information from the FRA grade crossing inventory records and the 20-second time period were used to calculate the distance the horns would be blown on a grade crossing by grade crossing basis.

This change in procedure resulted in a reduction in the impact and severe impact areas for many of the grade crossings under study. All grade crossings with the timetable speed less than the critical speed of 45 mph would have a shorter distance covered in the 20 seconds of time and the corresponding noise impact area would be less. For speeds at or greater than 45 mph, the impact area would be the same as in the initial analysis where the horn sounding starts at 1/4 mile.

A similar effect would occur for a 15-second horn sounding period, but with a critical speed of 60 mph rather than 45 mph. This means that impact polygons for all grade crossings with timetable speeds less than 60 mph will be shorter than 1/4 mile, a condition which results in many more grade crossings with shortened impact polygons than for the 20-second sounding period. Consequently, a 15-second limit results in less impact area than the 20-second period, but with less warning time provided.

Maximum Sound Level The impact assessment used a reference wayside sound exposure level (SEL) of 110 dBA at the grade crossing 100 feet from the tracks. This SEL was based on an extensive number of measurements throughout the country for this project and others by HMMH and the Volpe National Transportation Research Center (Volpe Center). Besides SEL, the L_{max} of horns was measured for the moving trains at the wayside and a relationship between them was determined. However, the proposed rule contains a provision that would limit the maximum level in **front** of the locomotive.

In order to estimate the SEL at the wayside from the L_{max} in front of the locomotive, HMMH developed a model based on horn sounding characteristics measured by the Volpe Center[37]. Measurements of horns were taken 100 feet in front and around the sides of several stationary locomotives. Detailed information was obtained about the length of the long and short horn blasts,

---

[37] Keller, A., and Rickley, E. The Safety of Highway-Railroad Grade Crossings: Study of the Acoustic Characteristics of Railroad Horn Systems . Report No. DOT/FRA/ORD-93/25, June 1993

and the amount of time between each horn blast. These data were used to determine the relationship between L_{max} and SEL, taking account of the following parameters:

C L_{max} for both the long and short horn blasts.
C   Speed of the train.
C   Time associated with the sounding sequence.
C   Duration of the four horn blasts (long, long, short, long), and the time between each blast.
C   Rise time of the horn blasts.

Using this model, HMMH was able to determine the difference between the L_{max} at 100 ft in front of a locomotive and the SEL measured at 100 feet at the wayside, near the grade crossing. This relationship was then used with the collected horn noise data to estimate a reference SEL based on capping the maximum horn sound at 104 dBA and 111 dBA at 100 feet in front of the locomotive.

Directivity The impact assessment assumed existing directivity for the horns. The model was based on empirical measurements, which included a mix of front and middle mounted horns. The reference SEL of 110 dBA represented an average over the entire locomotive fleet. The proposed rule contains a provision to limit the L_{max} from horns at the wayside to the maximum level at the front of the locomotive.

HMMH looked at the directivity pattern of a front mounted and center mounted horn obtained by measurements by the Volpe Center[38]. The Volpe Center showed that a horn mounted in the center of a locomotive tends to have a higher sound level to the side relative to the sound level to the front, while a horn mounted on the front of a locomotive tends to have a lower sound level to the side relative to the sound level to the front. Consequently, to approximate the noise effect of the provision, it was assumed that all horns to the front.

An estimate of the effect on the average SEL from moving all the horns to the front of the locomotives required estimating the mix of front and center mounted horns in the current locomotive fleet. The locomotive rosters for two of the largest Class I railroads, Union Pacific and Norfolk Southern, were reviewed along with photographs of typical locomotives of each type. Together they represent about 40% of the total locomotive fleet in the country. Assuming the horn positions in the photographs were typical, it was found that there are roughly an equal number of front mounted and middle mounted horns in their fleets (48% front, 52% middle) . For modeling purposes, a split of 50% front- and 50% middle-mounted horns was used to represent the current locomotive fleet. Using this information, and the difference in SEL based on horn location, HMMH was able to estimate the change in SEL due to moving all the horns to the front of the locomotives.

---

[38] *Ibid.*

5.2.3.1 *Results And Conclusions*

For the horn sounding sequence, the analysis resulted in a change in the total impact and severe impact area with no change in the input SEL because the distance changed over which horns were sounded. For the maximum level and directivity provisions, the change in SEL altered the noise impact at all grade crossings. Table 5.2 shows the SEL associated with each of the L_{max} limitations used for these provisions.

Table 5.3 presents the areas of impact and severe impact in square feet and square miles for the aggregate total of crossings under study for each of the provisions above. The severe impact area is a subset of the impact area, so that the severe impact area duplicates and is a part of the total impact area.   The percentages represent the percentage of the original 1/4 mile length areas. For each case, the 1/4 mile, 20 second, and 15 second lengths were calculated. Subsequently, this methodology was applied to an average crossing derived from the inventory database of all public highway-rail grade crossings nationwide. The potential national population relieved from existing train horn noise exposure was estimated using 1990 Census tract data, and is reported in the DEIS.

Table 5.2   Wayside SEL at 100 Feet Used for Each Condition

Condition	Location of Horns	SEL (dBA)
Original Condition	Mix	110
104 dBA L_{max} cap 100 feet in front of loco	Mix	108
	Front	105
111 dBA L_{max} cap 100 feet in front of loco	Mix	110
	Front	110

Table 5.3 Impact and Severe Impact Areas for Each Condition

Condition		1/4 Mile Length		20 Second Length		15 Second Length	
		Impact	Severe Impact	Impact	Severe Impact	Impact	Severe Impact
Original Condition, horns mixed	square feet (billion)	8.176	4.027	5.270	2.577	4.375	2.126
	square miles	293	144	189	92	157	76
% of Original, (1/4 mile length)		--	--	64.5	63.9	53.6	52.8
Cap Horn Lmax at 111, horns mixed	square feet (billion)	No Change from the Original Condition					
	square miles						
% of Original, (1/4 mile length)							
Cap Horn Lmax at 111, horns at front	square feet (billion)	No Change from the Original Condition					
	square miles						
% of Original, (1/4 mile length)							
Cap Horn Lmax at 104, horns mixed	square feet (billion)	6.098	2.559	3.841	1.541	3.161	1.243
	square miles	219	92	138	55	113	45
% of Original, (1/4 mile length)		74.7	63.9	47.1	38.2	38.6	31.3
Cap Horn Lmax at 104, horns at front	square feet (billion)	2.861	0.807	1.513	0.361	1.173	0.269
	square miles	103	29	54	13	42	10
% of Original, (1/4 mile length)		35.2	20.1	18.4	9.0	14.3	6.9
Cap night Lmax at 104, day Lmax at 111, horns mixed	square feet (billion)	7.114	3.408	4.573	2.177	3.796	1.797
	square miles	255	122	164	78	136	64
% of Original, (1/4 mile length)		87.0	84.7	56.0	54.2	46.4	44.4
Cap night Lmax at 104, day Lmax at 111, horns at front	square feet (billion)	5.430	2.344	3.452	1.462	2.856	1.196
	square miles	195	84	124	52	102	43
% of Original, (1/4 mile length)		66.6	58.3	42.3	36.1	34.8	29.9

APPENDIX A. TRAIN HORN NOISE MEASUREMENT PROGRAM

Noise measurements of train horns were carried out in residential areas near two at-grade crossings of main line railroad tracks in North Carolina between July 22 and July 24, 1998. The measurements were performed by the staff of Harris Miller Miller & Hanson Inc. (HMMH) for the U.S. Federal Railroad Administration (FRA), under subcontract to Parsons Transportation Group (PTG). The objective of the measurement program was to obtain representative field data for train horn noise in support of the noise model being developed to assess the potential noise impacts of the proposed Use of Locomotive Horns Rule. The measurement locations, procedures, equipment and results are described below.

A.1   MEASUREMENT LOCATIONS

Potential noise measurement sites were initially identified by HMMH based on a review of topographic maps of the areas along the north-south main lines of the two major freight railroads in North Carolina, operated by the Norfolk Southern Corporation (NS) and CSX Transportation (CSX). These lines were selected because they carry a high-volume of train traffic with a variety of equipment, including both freight and Amtrak passenger operations. Candidate sites were identified from the maps at grade crossings in residential areas that were at least one-half mile from any other grade crossing. Based on subsequent field reconnaissance, two (2) grade crossing sites were selected for the measurements. These sites included one grade crossing along the NS main line in a suburban residential area in North Kannapolis, NC (north of Charlotte) and a second grade crossing in a rural residential area along the CSX main line in Wade, NC (north of Fayetteville). The general location of these sites is shown in Figure A-1 and the specific noise measurement locations at these sites are described below.

A.1.1   *Site 1 - NS East 29th Street Grade Crossing in North Kannapolis, NC*

Noise measurements were carried out on July 22-23, 1998 at six locations in the vicinity of the East 29th Street grade crossing (ID # 724397M) of the NS single-track main line in North Kannapolis, NC (see photograph in Figure A-2). As shown in plan view in Figure A-3, all microphone locations were to the north of East 29th Street, and thus were subject to the greatest horn noise exposure from southbound trains approaching the grade crossing. The specific measurement locations are described below.

Position 1. Microphone Position 1 (see photograph in Figure A-4) was located closest to the grade crossing at 100 feet east of the track center line and 100 feet north of the East 29th Street center line. The microphone was located in an open field to the south of the first row of houses along Kirk Avenue, a gravel road that runs along the east side of the track. This position was selected to represent an unshielded neighborhood location close to the grade crossing.

Position 2. Microphone Position 2 (see photograph in Figure A-5) was located behind the house at 111 East 29th Street, at 450 feet east of the track centerline and 100 feet north of the East 29th Street center line. The microphone was located in the back yard of this home, partially shielded from the track by one or two rows of houses. This position was selected to represent a partially-shielded neighborhood location close to the grade crossing.

Position 3. Microphone Position 3 (see photograph in Figure A-6) was located in front of the house at 109 East 31st Street, at 100 feet east of the track center line and about 900 feet north of East 29th Street. The microphone was located in the front yard of this home, about 5 feet from the edge of the street. This position was selected to represent a minimally-shielded neighborhood location close to the track where southbound trains sound their horns.

Position 4. Microphone Position 4 (see photograph in Figure A-7) was located behind the house at 200 East 31st Street, at about 500 feet east of the track center line and about 800 feet north of East 29th Street. The microphone was located in the backyard of this home, partially-shielded from the track by two or three rows of houses. This position was selected to represent a partially-shielded location in the middle of the neighborhood.

Position 5. Microphone Position 5 (see photograph in Figure A-8) was located at 100 feet east of the track center line and about 500 feet north of East 29th Street. The microphone was located at the edge of a wooded area to the north of the first row of houses along Kirk Avenue. This position was selected to represent an unshielded neighborhood location about half-way between microphone Positions 1 and 3.

Position 6. Microphone Position 6 (see photograph in Figure A-9) was located near a church parking lot at about 900 feet east of the track center line and about 700 feet north of East 29th Street. The microphone was located in an open field, 150 feet west of Chapel Street and 30 feet south of East 30th Street, shielded from the track by three to five rows of houses. This position was selected to represent a neighborhood location in the vicinity of the grade crossing that is fairly well shielded from train horn noise.

A.1.2   Site 2 - CSX Church Street Grade Crossing in Wade, NC

Noise measurements were carried out on July 23-24, 1998 at six locations in the vicinity of the Church Street grade crossing (ID # 629 869 Y) of the single-track main line at CSX Milepost A 198.36 in Wade, NC (see photograph in Figure A-10). As shown in plan view in Figure A-11, all microphone locations were to the south of Church Street, and thus were subject to the greatest horn noise exposure from northbound trains approaching the grade crossing. The specific measurement locations are described below.

Position 1. Microphone Position 1 (see photograph in Figure A-12) was located closest to the grade crossing at 100 feet east of the track center line and 100 feet south of the Church Street center line. The microphone was located in the back yard of the home at 4000 Church Street to the north of the first row of houses along Lee Street, a dead-end road that runs along the east side of the track. This position was selected to represent an unshielded neighborhood location close to the grade crossing.

Position 2. Microphone Position 2 (see photograph in Figure A-13) was located behind the house at 4012 Church Street, about 300 feet east of the track centerline and 200 feet south of the Church Street center line. The microphone was located in the back yard of this home, partially shielded from the track by one or two rows of houses. This position was selected to represent a partially-shielded neighborhood location close to the grade crossing.

Position 3. Microphone Position 3 (see photograph in Figure A-14) was located in front of the house at 7165 Lee Street, at 100 feet east of the track center line and about 650 feet south of Church Street. The microphone was located in the front yard of this home, about 10 feet from the edge of the street. This position was selected to represent a minimally-shielded neighborhood location close to the track where northbound trains sound their horns.

Position 4. Microphone Position 4 (see photograph in Figure A-15) was located behind the house at 7180 Lee Street, at 250 feet east of the track center line and about 450 feet south of Church Street. The microphone was located at the rear property line of this home, partially-shielded from the track by one row of houses. This position was selected to represent a partially-shielded location in the middle of the neighborhood.

Position 5. Microphone Position 5 (see photograph in Figure A-16) was located along the first row of houses on Lee Street, at 100 feet east of the track center line and about 300 feet south of Church Street. The microphone was located in an open lot adjacent to the home at 7184 Lee Street. This position was selected to represent an unshielded neighborhood location about half-way between microphone Positions 1 and 3.

Position 6. Microphone Position 6 (see photograph in Figure A-17) was located behind the home at 4026 Church Street, about 700 feet east of the track center line and about 150 feet south of Church Street. The microphone was located in the back yard of the home near Pecan Avenue, shielded from the track by one to three rows of houses. This position was selected to represent a neighborhood location in the vicinity of the grade crossing that is fairly well shielded from train horn noise.

A.2 MEASUREMENT PROCEDURES AND EQUIPMENT

All noise measurements were made using equipment that conforms to ANSI Standard S1.4 for precision (Type 1) sound level meters. The measurements were made using one-half inch pre-polarized condenser microphones protected by foam windscreens and supported by tripods at a height of approximately 5 feet above the ground. For both grade crossing sites, the same instrumentation system was used at each microphone position. At positions 1 through 4, portable noise monitors were installed, set to "fast" response, and programmed to automatically collect continuous time-history and hourly statistical data for the A-weighted sound level. At microphone positions 5 and 6, train noise signals were amplified and recorded on magnetic tape using Digital Audio Tape (DAT) recorders. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST), were carried out before and after each set of measurements in the field using acoustical calibrators. A list of the field instrumentation, including manufacturers, models and serial numbers, is provided in Table B-1.

At grade crossing Site 1 in Kannapolis, noise monitor data at measurement positions 1 through 4 were collected for a total of 32 trains between 12:00 PM on July 22 and 11:00 AM on July 23. Of these, noise data were obtained at measurement positions 1 through 6 for a total of 14 trains that were observed at this site between 3:00 PM and 9:00 PM on July 22 and between 8:00 AM and 11:00 AM on July 23.

At grade crossing Site 2 in Wade, noise monitor data at measurement positions 1 through 4 were collected for a total of 18 trains between 8:00 PM on July 23 and 2:00 PM on July 24. Of these, noise data were obtained at measurement positions 1 through 6 for a total of 7 trains that were observed at this site between 10:00 AM and 2:00 PM on July 24.

During the periods when trains were observed, train speeds were measured using a radar speed detector, and each train event was documented on videotape to provide a record of specific train operation and consist details. Additional documentation was provided on field data sheets and by voice annotations on the audio and video recordings.

Analysis of the field data was carried out in the HMMH laboratory. For data collected by the noise monitors at measurement positions 1-4, the continuous time histories were transferred to computer records for subsequent calculation of the maximum A-weighted sound level (L_{max}) and Sound Exposure Level (SEL) for each train event and measurement position at each grade crossing site. For measurement positions 5 and 6, these parameters were obtained from the tape-recorded data using a Larson Davis Model 2900 noise analyzer. The noise measurement results are summarized below in Section A.3.

Table A-1. Field Instruments Used for Train Horn Noise Measurements

Measurement Position	Instrumentation Data			
	Type	**Manufacturer**	**Model**	**Serial Number**
1	Microphone	Bruel & Kjaer	4155	1817577
	Pre-Amplifier	Larson Davis	900B	1479
	Noise Monitor	Larson Davis	870A	0193
	Calibrator	Gen Rad	1987	8103665006
2	Microphone	Bruel & Kjaer	4189	2021340
	Pre-Amplifier	Larson Davis	900B	3730
	Noise Monitor	Larson Davis	870A	0283
	Calibrator	Gen Rad	1987	2933
3	Microphone	Bruel & Kjaer	4155	1932425
	Pre-Amplifier	Larson Davis	900B	1419086
	Noise Monitor	Larson Davis	870A	0256
	Calibrator	Bruel & Kjaer	4231	1859542
4	Microphone	Bruel & Kjaer	4189	2008916
	Pre-Amplifier	Larson Davis	900B	2880
	Noise Monitor	Larson Davis	870A	0556
	Calibrator	Gen Rad	1987	2880
5	Microphone	Gen Rad	1962-9610	11646
	Pre-Amplifier	Gen Rad	1972-9600	DA1S
	Amplifier	EPAC	60/10 LN	114
	Tape Recorder	SONY	TCD-D7	76865
	Calibrator	Gen Rad	1987	8103665006
6	Microphone	Gen Rad	1962-9610	15837
	Pre-Amplifier	Gen Rad	1972-9600	DA4
	Amplifier	EPAC	60/10 LN	224
	Tape Recorder	SONY	Pro DAT 10	122526
	Calibrator	Gen Rad	1987	8103665006

A.3 MEASUREMENT RESULTS

Complete horn noise measurement results are provided in Tables A-2 through A-5. Detailed noise data for all 50 train events monitored at Site 1 and Site 2 are included in Tables A-2 and A-3, respectively. These tables list the L_{max}(fast) and SEL values measured at microphone positions 1 through 4 for each site, as well as the date, time and direction for each train. For trains that were not visually observed, the direction of travel was determined based on the level of noise recorded at microphone Position 3, located about 1/8-mile from the grade crossing. Detailed noise data for the 21 trains observed at Site 1 and Site 2 are provided in Tables A-4 and A-5, respectively. These tables list the L_{max}(fast) and SEL values measured at microphone positions 1 through 6 for each site, as well as detailed information on the train consist, speed, direction and horn operation.

A review of the horn operational data included in Tables A-4 and A-5 indicates a wide variety of horn operating practices as follows:

C   Trains began their horn sequence at distances that varied from 440 feet to 2,110 feet from to the grade crossing, with an average distance of 1,100 feet; there was no apparent correlation between this distance and train speed.

C   The overall interval for the horn sequence varied from 9 seconds to 55 seconds, with an average interval of 18 seconds. During the horn sequence, horns were sounded for total durations that varied from 6 seconds to 28 seconds, with an average duration of 11 seconds.

C   The number of discrete horn blasts varied from 1 to 7 blasts, with an average of 4 blasts.

A summary of the train horn noise measurement data is provided in Table A-6. These results indicate maximum horn noise levels of up to 110 dBA at 100 feet from the track center line. For trains approaching the grade crossings, the SEL values measured at 100 feet from the track were fairly consistent at positions between 1/8-mile and 100 feet from the crossings, with an average value of 111 dBA. At community locations ranging between 250 feet and 900 feet from the track, the measured SEL values were about 10 to 20 dBA lower than at 100 feet due to the effects of distance, ground absorption and shielding.

In terms of daily noise exposure, the noise monitor data at 100 feet from the tracks indicated average day-night equivalent sound levels (L_{dn}) of 80 dBA at Site 1 and 78 dBA at Site 2. Based on the data for L_{33} (the sound level exceeded 33 percent of the time), it is estimated that the background L_{dn} (i.e., without the train noise) averaged 57 dBA in the vicinity of Site 1 and 55 dBA in the vicinity of Site 2. Thus, it can be concluded that train horn noise dominated the noise environment at all measurement positions.

Table A-2. Noise Monitor Data for Trains Horns at Site 1 (NS/N. Kannapolis, NC)

Train Event Information				Maximum Noise Level (L$_{max}$fast), dBA				Sound Exposure Level (SEL), dBA			
No.	Date	Time	Dir.	Pos. 1 (100 ft)	Pos. 2 (450 ft)	Pos. 3 (100 ft)	Pos. 4 (500 ft)	Pos. 1 (100 ft)	Pos. 2 (450 ft)	Pos. 3 (100 ft)	Pos. 4 (500 ft)
1	7/22/98	12:23	NB	104	81	89	81	107	87	98	87
2	7/22/98	12:59	SB	103	88	103	86	110	96	108	95
3	7/22/98	13:49	SB	107	92	107	84	107	98	113	94
4	7/22/98	14:01	NB	99	80	88	81	107	88	99	90
5	7/22/98	15:57	SB	105	91	106	90	112	98	113	97
6	7/22/98	17:00	NB	99	78	77	84	101	88	88	91
7	7/22/98	17:23	NB	102	81	77	83	106	87	84	90
8	7/22/98	18:04	NB	105	82	89	82	113	90	99	91
9	7/22/98	18:18	NB	102	77	72	81	106	82	78	87
10	7/22/98	18:46	NB	97	77	90	79	103	85	96	86
11	7/22/98	19:10	NB	101	81	89	86	105	89	97	91
12	7/22/98	20:16	SB	105	92	101	87	112	100	107	97
13	7/22/98	20:26	SB	106	90	107	89	109	97	111	96
14	7/22/98	21:39	NB	103	90	91	87	107	95	100	92
15	7/22/98	22:28	SB	101	90	103	85	105	96	108	92
16	7/22/98	23:52	SB	102	90	101	77	108	98	108	84
17	7/23/98	00:10	NB	104	83	88	92	109	93	96	101
18	7/23/98	01:49	SB	105	91	106	86	109	97	110	93
19	7/23/98	02:09	SB	99	79	95	84	105	89	104	91
20	7/23/98	02:22	NB	104	85	80	93	107	91	87	98
21	7/23/98	05:13	SB	105	91	106	83	109	97	110	92
22	7/23/98	05:30	SB	103	90	106	87	107	98	112	95
23	7/23/98	05:40	SB	106	89	107	91	109	96	111	97
24	7/23/98	05:55	NB	100	78	68	86	102	86	77	93
25	7/23/98	06:41	SB	103	91	106	88	105	93	108	90
26	7/23/98	06:47	NB	102	79	80	92	109	89	89	97
27	7/23/98	07:59	SB	96	76	94	82	104	88	102	89

Train Event Information				Maximum Noise Level (L$_{max}$fast), dBA				Sound Exposure Level (SEL), dBA			
No.	Date	Time	Dir.	Pos. 1 (100 ft)	Pos. 2 (450 ft)	Pos. 3 (100 ft)	Pos. 4 (500 ft)	Pos. 1 (100 ft)	Pos. 2 (450 ft)	Pos. 3 (100 ft)	Pos. 4 (500 ft)
28	7/23/98	08:38	NB	104	85	78	92	104	92	93	97
29	7/23/98	09:27	NB	105	84	88	90	109	91	95	98
30	7/23/98	09:33	NB	102	80	77	87	109	89	85	94
31	7/23/98	09:57	NB	108	87	76	95	114	95	84	102
32	7/23/98	10:56	SB	100	88	103	85	104	93	107	90

Table A-3. Noise Monitor Data for Train Horns at Site 2 (CSX/Wade, NC)

Train Event Information				Maximum Noise Level (L$_{max}$fast), dBA				Sound Exposure Level (SEL), dBA			
No.	Date	Time	Dir.	Pos. 1 (100 ft)	Pos. 2 (300 ft)	Pos. 3 (100 ft)	Pos. 4 (250 ft)	Pos. 1 (100 ft)	Pos. 2 (300 ft)	Pos. 3 (100 ft)	Pos. 4 (250 ft)
1	7/23/98	20:58	SB	102	88	85	84	106	91	90	89
2	7/24/98	00:52	SB	94	87	74	78	97	90	79	82
3	7/24/98	01:16	SB	101	87	93	81	104	88	98	89
4	7/24/98	01:52	SB	106	93	87	81	108	97	90	86
5	7/24/98	01:59	NB	105	93	106	99	111	100	112	103
6	7/24/98	03:04	NB	104	96	105	100	107	100	109	105
7	7/24/98	04:22	SB	102	85	97	88	103	91	101	92
8	7/24/98	04:31	SB	100	82	88	81	103	86	91	84
9	7/24/98	06:26	SB	97	87	76	78	101	89	80	82
10	7/24/98	07:52	NB	107	93	109	100	111	101	115	105
11	7/24/98	08:16	NB	105	92	108	98	109	98	112	101
12	7/24/98	10:09	NB	106	91	109	99	110	98	114	104
13	7/24/98	10:32	NB	104	94	107	97	108	98	110	101
14	7/24/98	10:52	NB	104	87	101	94	108	93	106	98
15	7/24/98	11:43	NB	107	91	104	99	110	98	110	104
16	7/24/98	12:33	NB	106	93	108	102	112	100	113	107
17	7/24/98	12:54	NB	104	91	107	98	106	94	110	102
18	7/24/98	13:10	NB	104	87	105	99	108	93	108	102

Table A-4. Horn Noise Measurement Data for Observed Trains at Site 1
(NS/N. Kannapolis, NC)

Train No.	Train Description					Horn Operation Data			Meas. Location		Noise Level (dBA)	
	Type	# of Loc	# of Cars	Speed (mph)	Dir.	Horn Start Distance from GX (ft)	Horn Dur. /Seq. (sec)	No. of Horn Blasts	Mic. Pos.	Distance from Track CL (ft)	Lmax (fast)	SEL
5	Freight	1 (CR)	22	45	SB	1,060	14/16	4	1	100	105	112
									2	450	91	98
									3	100	106	113
									4	500	90	97
									5	100	107	110
									6	900	85	89
6	Freight	3 (NS)	37	45	NB	590	8/9	4	1	100	99	101
									2	450	78	88
									3	100	77	88
									4	500	84	91
									5	100	82	88
									6	900	84	88
7	Freight	1 (NS)	2	53	NB	910	11/13	3	1	100	102	106
									2	450	81	87
									3	100	77	84
									4	500	83	90
									5	100	78	84
									6	900	86	89
8	Freight	2 (NS)	165	22	NB	1,770	28/55	6	1	100	105	113
									2	450	82	90
									3	100	89	99
									4	500	82	91
									5	100	89	98
									6	900	82	88

Train No.	Train Description					Horn Operation Data			Meas. Location		Noise Level (dBA)	
	Type	# of Loc	# of Cars	Speed (mph)	Dir.	Horn Start Distance from GX (ft)	Horn Dur. /Seq. (sec)	No. of Horn Blasts	Mic. Pos.	Distance from Track CL (ft)	Lmax (fast)	SEL
9	Amtrak (Pass)	2	4	27	NB	440	7/11	4	1	100	102	106
									2	450	77	82
									3	100	72	78
									4	500	81	87
									5	100	79	84
									6	900	77	80
10	Freight	3 (NS)	82	33	NB	1,260	16/27	5	1	100	97	103
									2	450	77	85
									3	100	90	96
									4	500	79	86
									5	100	89	94
									6	900	76	74
11	Freight	3 (NS)	104	33	NB	970	14/20	4	1	100	101	105
									2	450	81	89
									3	100	89	97
									4	500	86	91
									5	100	89	96
									6	900	86	89
12	Freight	3 (NS)	114	38	SB	780	13/14	4	1	100	105	112
									2	450	92	100
									3	100	101	107
									4	500	87	97
									5	100	107	113
									6	900	84	90

Train No.	Train Description					Horn Operation Data			Meas. Location		Noise Level (dBA)	
	Type	# of Loc	# of Cars	Speed (mph)	Dir.	Horn Start Distance from GX (ft)	Horn Dur./Seq. (sec)	No. of Horn Blasts	Mic. Pos.	Distance from Track CL (ft)	Lmax (fast)	SEL
13	Amtrak (Pass)	1	7	60	SB	2,110	13/24	4	1	100	106	109
									2	450	90	97
									3	100	107	111
									4	500	89	96
									5	100	107	109
									6	900	85	89
28	Amtrak (Pass)	1	7	60	NB	1,580	12/18	7	1	100	104	104
									2	450	85	92
									3	100	78	93
									4	500	92	97
									5	100	83	88
									6	900	61	69
29	Freight	2 (NS)	44	40	NB	590	9/10	4	1	100	105	109
									2	450	84	91
									3	100	88	95
									4	500	90	98
									5	100	91	95
									6	900	71	78
30	Freight	1 (NS)	11	28	NB	780	11/19	7	1	100	102	109
									2	450	80	89
									3	100	77	85
									4	500	87	94
									5	100	88	93
									6	900	86	91

Train No.	Train Description					Horn Operation Data			Meas. Location		Noise Level (dBA)	
	Type	# of Loc	# of Cars	Speed (mph)	Dir.	Horn Start Distance from GX (ft)	Horn Dur. /Seq. (sec)	No. of Horn Blasts	Mic. Pos.	Distance from Track CL (ft)	Lmax (fast)	SEL
31	Freight	3 (NS)	132	35	NB	670	13/13	1	1	100	108	114
									2	450	87	95
									3	100	76	84
									4	500	95	102
									5	100	70	77
									6	900	90	96
32	Amtrak (Pass)	1	4	60	SB	1,410	13/16	4	1	100	100	104
									2	450	88	93
									3	100	103	107
									4	500	85	90
									5	100	103	105
									6	900	79	83

Table A-5. Horn Noise Measurement Data for Observed Trains at Site 2 (CSX/Wade, NC)

Train No.	Train Description					Horn Operation Data			Meas. Location		Noise Level (dBA)	
	Type	# of Loc	# of Cars	Speed (mph)	Dir.	Horn Start Distance from GX (ft)	Horn Dur. /Seq. (sec)	No. of Horn Blasts	Mic. Pos.	Distance from Track CL (ft)	Lmax (fast)	SEL
12	Freight	3	37	65	NB	1,530	8/16	4	1	100	106	110
									2	300	91	98
									3	100	109	114
									4	250	99	104
									5	100	110	115
									6	700	88	93
13	Amtrak (Pass)	2	12	79	NB	1,510	10/13	4	1	100	104	108
									2	300	94	98
									3	100	107	110
									4	250	97	101
									5	100	110	111
									6	700	89	91
14	Freight	2	77	38	NB	950	6/17	7	1	100	104	108
									2	300	87	93
									3	100	101	106
									4	250	94	98
									5	100	108	110
									6	700	84	87
15	Freight	3	129	38	NB	840	9/15	3	1	100	107	110
									2	300	91	98
									3	100	104	110
									4	250	99	104
									5	100	109	115
									6	700	84	89

Train No.	Train Description					Horn Operation Data			Meas. Location		Noise Level (dBA)	
	Type	# of Loc	# of Cars	Speed (mph)	Dir.	Horn Start Distance from GX (ft)	Horn Dur. /Seq. (sec)	No. of Horn Blasts	Mic. Pos.	Distance from Track CL (ft)	Lmax (fast)	SEL
16	Freight	4	130	48	NB	1,200	12/17	5	1	100	106	112
									2	300	93	100
									3	100	108	113
									4	250	102	107
									5	100	110	115
									6	700	85	90
17	Freight	2	73	41	NB	1,140	6/19	4	1	100	104	106
									2	300	91	94
									3	100	107	110
									4	250	98	102
									5	100	109	110
									6	700	80	84
18	Freight	2	93	44	NB	1,030	8/16	4	1	100	104	108
									2	300	87	93
									3	100	105	108
									4	250	99	102
									5	100	110	112
									6	700	76	82

Table A-6. Summary of Train Horn Noise Measurement Data

Site No.	Mic. Pos.	Distance from Track Center Line (ft)	Distance from Grade-Crossing Road Center Line (ft)	Arithmetic Average L_{max} (dBA)		Energy Average SEL (dBA)	
				NB Trains	SB Trains	NB Trains	SB Trains
1	1	100	100	102	103	108	108
	2	450	100	82	89	90	97
	3	100	900	82	103	95	110
	4	500	800	87	86	96	94
	5	100	500	84	106	93	110
	6	900	700	80	83	89	88
2	1	100	100	105	100	109	104
	2	300	200	92	87	98	92
	3	100	650	106	86	112	95
	4	250	450	99	82	104	88
	5	100	300	109	84	113	(None Meas.)
	6	700	150	84	80	89	(None Meas.)
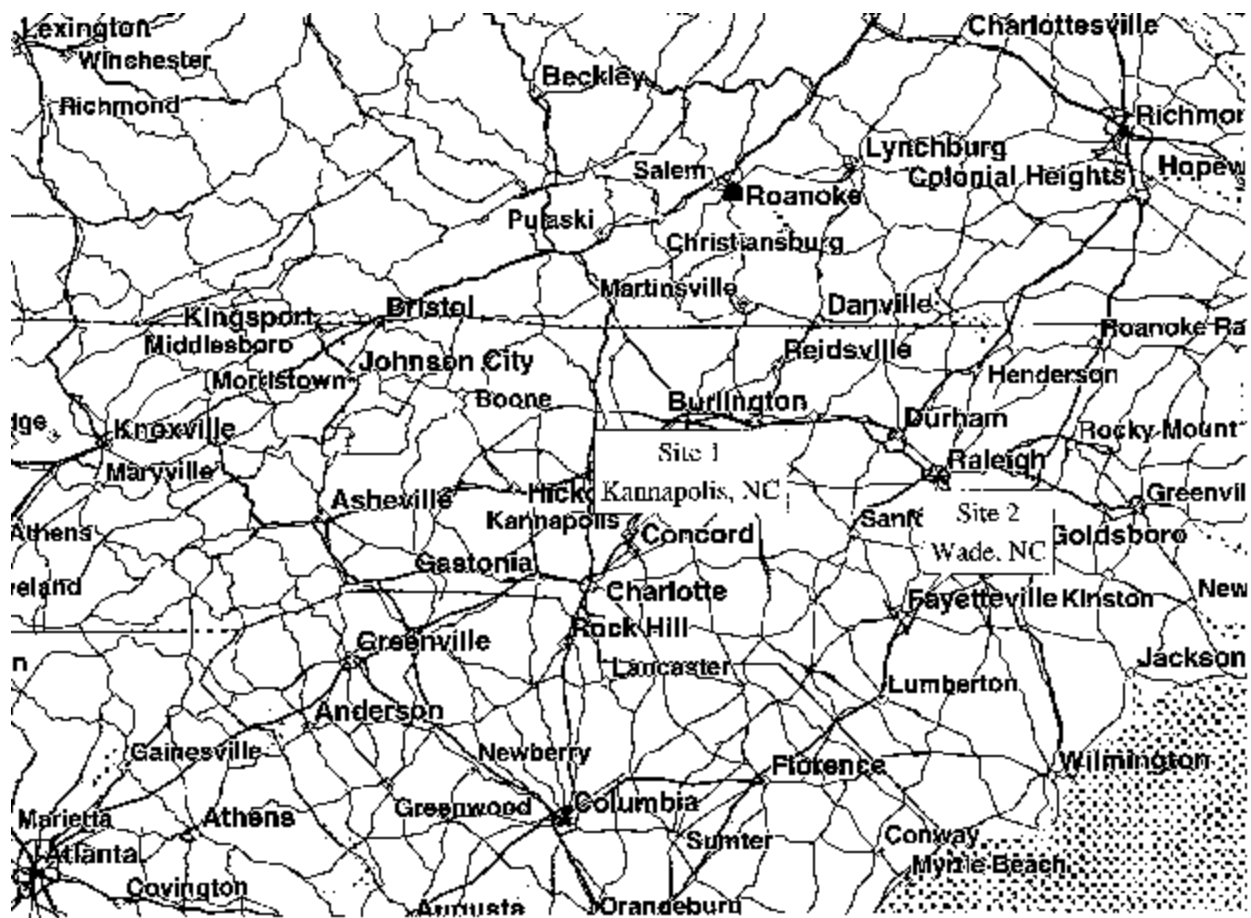
Figure A-1. Locations of Train Horn Noise Measurement Sites in North Carolina

Figure A-2. NS East 29th Street Grade Crossing in North Kannapolis, NC
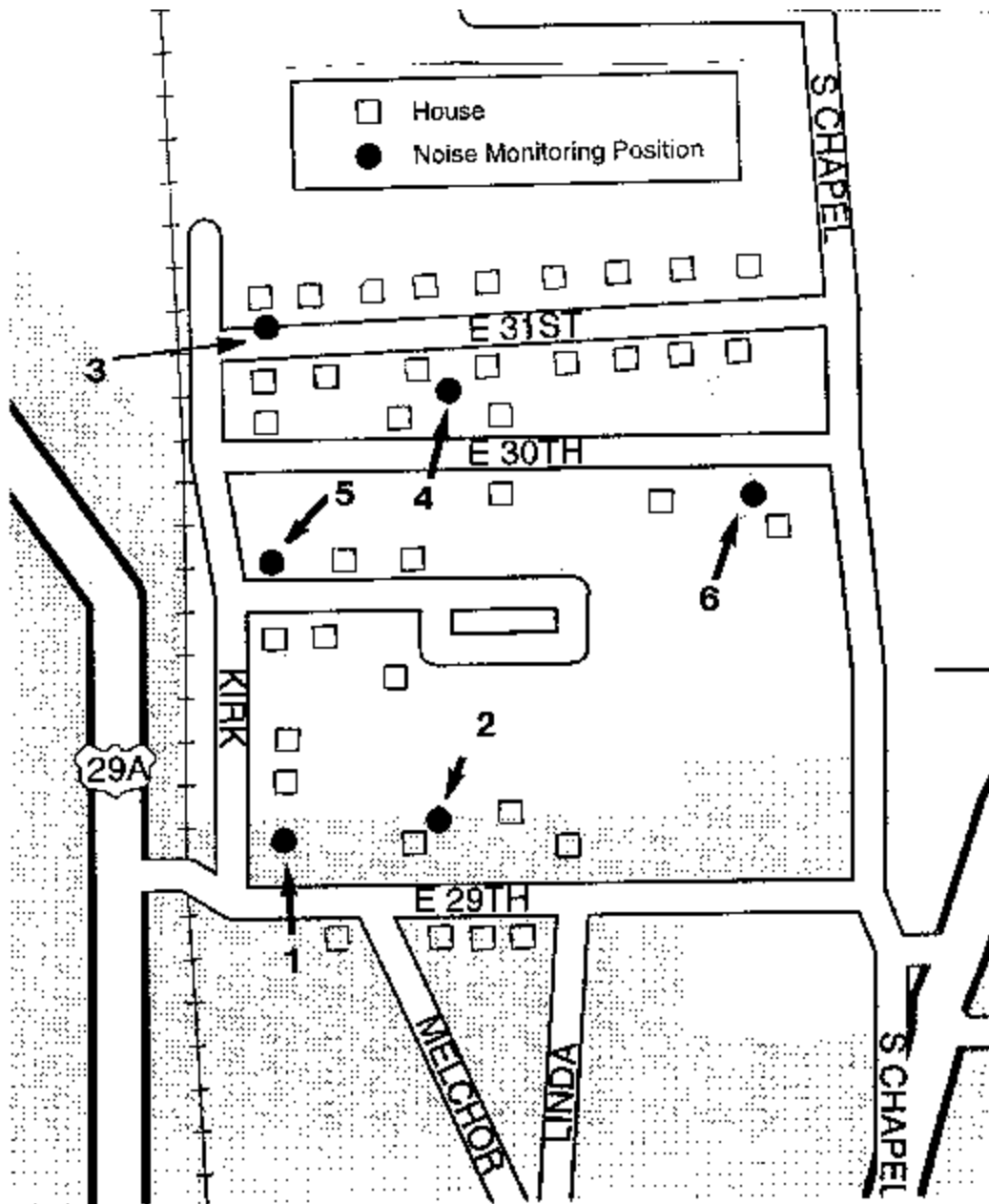
Figure A-3. Noise Measurement Locations at Grade Crossing Site 1

Figure A-4. Microphone Position 1 at Grade Crossing Site 1

Figure A-5. Microphone Position 2 at Grade Crossing Site 1

Figure A-6. Microphone Position 3 at Grade Crossing Site 1

Figure A-7. Microphone Position 4 at Grade Crossing Site 1

Figure A-8. Microphone Position 5 at Grade Crossing Site 1

Figure A-9. Microphone Position 6 at Grade Crossing Site 1

Figure A-10. CSX Church Street Grade Crossing in Wade, NC
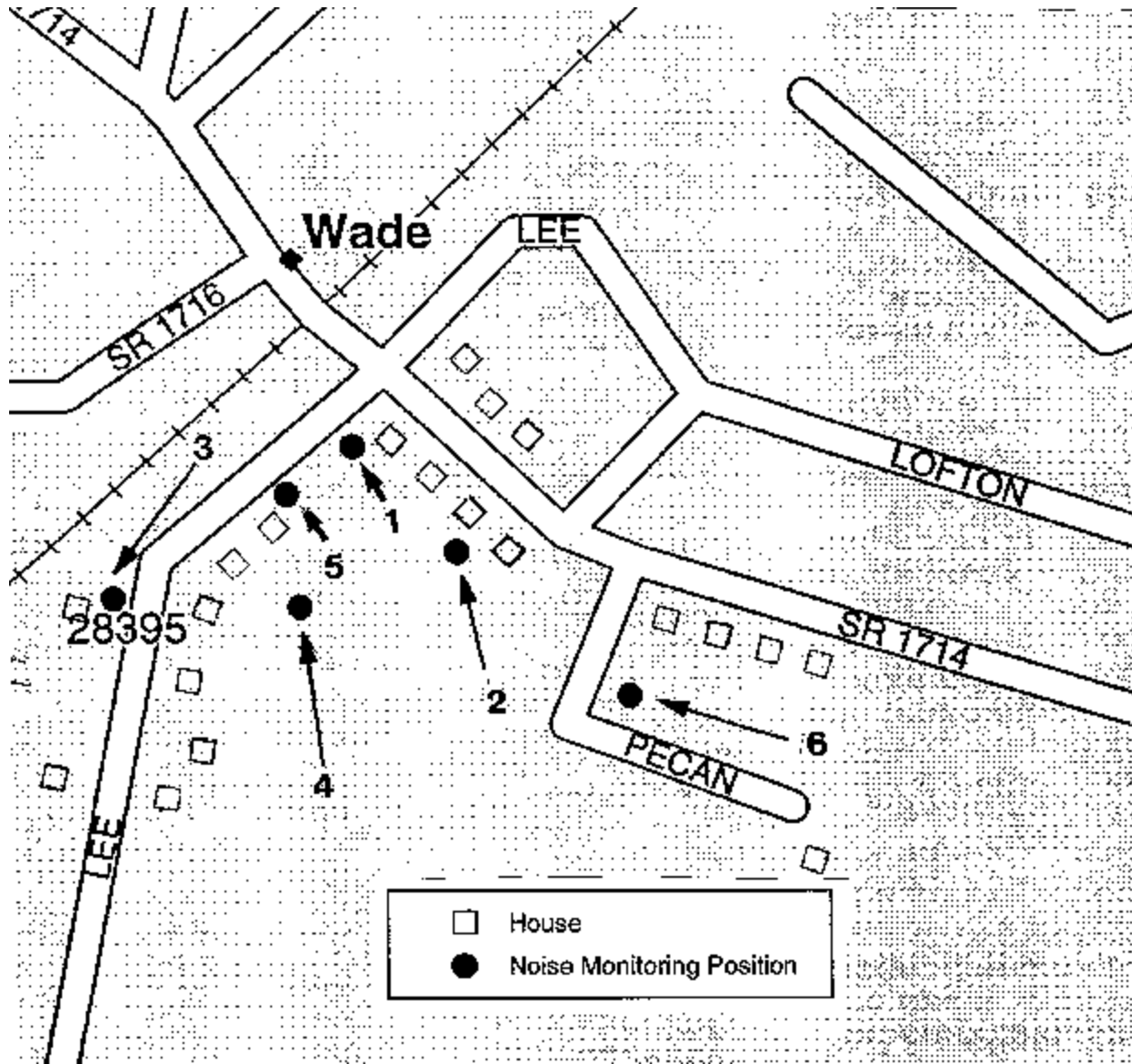
Figure A-11. Noise Measurement Locations at Grade Crossing Site 2

Figure A-12. Microphone Position 1 at Grade Crossing Site 2

Figure A-13. Microphone Position 2 at Grade Crossing Site 2

Figure A-14. Microphone Position 3 at Grade Crossing Site 2

Figure A-15. Microphone Position 4 at Grade Crossing Site 2

Figure A-16. Microphone Position 5 at Grade Crossing Site 2

Figure A-17. Microphone Position 6 at Grade Crossing Site 2

APPENDIX B. DATA SHEETS

1. Measurement Data - CN/IC Merger, Harris Miller Miller & Hanson Inc.
     a. Microphone position 1 is at grade crossing

Table B-1. Relevant Measurement Data - CN/IC Railroad

Railroad	Site	Train No.	Before/After Crossing	Speed (mph)	Dist. from track CL	Mic Position (a)	Normalized to 100' Locomotives	
							Lmax	**SEL**
IC	Monee, IL	1	B	29	50	1	104.5	111.4
		2	B	63	50	1	99.5	102.4
		3	B	25	50	1	99.5	106.2
		5	B	51	50	1	107.5	108.3
		6	B	42	50	1	100.5	103.8
		8	B	48	50	1	109.5	111.9
		10	B	42	50	1	99.5	104.4
	Chebanse IL	2	B	51	50	1	100.5	103.2
		3	B	54	50	1	96.5	97.3
		4	B	61	50	1	100.5	103.6
		8	B	56	50	1	107.5	108.7
		9	B	58	50	1	99.5	100.8
		12	B	65	50	1	98.5	101.1
		15	B	41	50	1	95.5	98.9
CN	Highland IN	1	B	47	114	1	109.9	110.9
		8	B	41	114	1	103.9	109.2
		9	B	40	114	1	110.9	115.0
		10	B	47	114	1	109.9	116.0
		11	B	40	114	1	112.9	117.2
		14	B	46	114	1	110.9	112.9
		15	B	40	114	1	102.9	108.5
	Crumstown IN	3	B	55	64	1	105.1	107.0
		5	B	58	64	1	107.1	109.3
		6	B	43	64	1	109.1	109.8
		7	B	50	64	1	106.1	108.5
		8	B	48	64	1	109.1	111.6
		10	B	43	64	1	108.1	108.2
		11	B	60	64	1	114.1	114.3
		12	B	56	64	1	118.1	115.9
		13	B	48	64	1	105.1	107.1
		18	B	51	64	1	96.1	97.7
		20	B	52	64	1	100.1	99.3
		21	B	51	64	1	110.1	110.7
		22	B	54	64	1	114.1	114.2
		24	B	48	64	1	103.1	106.6
		25	B	42	64	1	111.1	112.4

2. Measurement Data - Norfolk Southern/CXS.Conrail Merger, Harris Miller Miller & Hanson.

Table B-2. CSX and Conrail Trains

Site	Train No.	Direc- tion	No. of Locos	No. of Cars	Speed (mph)	Dist. from Xing (ft)	Dist from Track (ft)	Sound Levels Lmax	SEL
Site 1-Powell, OH (CSX)							Nov. 19-20, 1996		
	1	SB	2	98	37	600	113	97	104.2
	2	NB	2	22	42	0	113	102	107.9
						600	113	103	109.1
						1200	113	97	101.5
	3	NB	2	148	18	0	100	107	115.0
						600	100	108	115.3
						1200	100	87	98.0
	4	SB	2	25	3	0	113	95	100.8
	5	SB	2	13	6	0	113	96	100.9
	6	NB	2	90	26	0	100	103	110.8
						600	100	104	112.7
						1200	100	101	107.3
Site 2 - Fostoria, OH (CSX)							Nov. 20-21, 1996		
	1	WB	3	100	35	0	100	104	108.6
	2	EB	2	148	39	0	113	100	104.7
	3	EB	3	54	39	0	113	101	106.3
	4	EB	6	84	26	0	113	105	108.5
	5	WB	2	48	30	0	100	108	114.9
	6	WB	4	110	32	0	100	108	113.3
	7	EB	2	69	38	0	113	101	107.8
Site 3 - Sandusky, OH (Conrail)							Nov. 20, 1996		
	1	EB	2	30	12	0	100	99	107.4
	2	EB	3	135	26	0	100	100	104.8
	3	EB	3	112	27	0	100	94	99.9
	4	EB	3	110	23	0	100	96	103.8
	5	EB	3	131	23	0	100	101	108.4
	6	WB	2	96	12	0	113	96	102.5
	7	WB	2	89	19	0	113	96	103.4
	8	WB	2	54	18	0	113	103	109.2
	9	WB	2	64	19	0	113	97	103.3
	10	WB	2	109	20	0	113	100	105.3
	11	EB	1	5	20	0	100	99	106.3
	12	WB	3	79	23	0	113	101	108.4

Site	Train No.	Direction	No. of Locos	No. of Cars	Speed (mph)	Dist. from Xing (ft)	Dist from Track (ft)	Sound Levels Lmax	SEL
Site 4 - LaRue, OH (Conrail)							Nov. 21-22, 1996		
	1	EB	2	28	37	0	85	105	110.6
	2	WB	6	0	-	0	85	100	104.8
	3	WB	3	108	43	0	85	100	107.9
	4	EB	2	54	49	0	85	103	109.8
	5	EB	3	117	48	0	85	105	110.4
	6	EB	2	66	58	0	85	99	106.5
						600	100	97	106.0
	7	EB	3	112	62	0	85	105	111.7
						600	100	104	110.6
	8	EB	3	81	60	0	85	99	104.2
						600	100	98	103.5
	9	WB	2	124	44	0	85	105	110.2
Site 5 - Leipsic, OH (CSX)							Nov. 21-22, 1996		
	1	SB	2	62	37	0	100	102	107.3
	2	NB	2	64	34	0	100	104	110.3
	3	NB	2	50	18	0	100	107	113.9

3. Measurement Data - Jacksonville, FL, Volpe Center

Table B-3. Florida East Coast Trains

Site	Train No.	Direc-tion	No. of Locos	No. of Cars	Speed (mph)	Dist. from Xing (ft)	Dist from Track (ft)	Sound Levels	
								Lmax	SEL
Sunbeam Road									
	1	NB	--	--	26	0	50	112.1	114.4
						0	200	101.3	107.2
	2	NB	--	--	35	0	50	103.7	107.3
						0	200	95.6	98.9
Shad Road									
	3	NB	--	--	47	0	75	96.8	98.1
						0	150	92.6	98.0
	4	NB	--	--	45	0	75	96.4	98.0
						0	150	92.8	98.2
Mussells Acres Road									
	5	SB	--	--	42	0	50	103.9	104.9
						0	200	90.9	98.4
	6	SB	--	--	43	0	50	105.2	110.2
						0	200	--	--
Old St. Augustine Road									
	7	SB	--	--	26	0	50	112.0	115.1
						0	200	98.0	106.1
	8	NB	--	--	18	0	50	107.2	109.4
						0	200	95.3	102.1
Greenland Road									
	9	NB	--	--	45	0	50	107.0	107.8
						0	200	93.9	102.5
	10	NB	--	--	59	0	50	102.7	107.7
						0	200	90.8	95.5
Cedar Street									
	11	NB	--	--	44	0	50	99.6	102.8
						0	200	88.0	93.5
	12	NB	--	--	25	0	50	101.9	105.1
						0	200	89.7	96.4

4. Measurement Data - Gering, Nebraska, Volpe Center

Table B-4. Union Pacific Trains

Site	Train No.	Direc- tion	No. of Locos	No. of Cars	Speed (mph)	Dist. from Xing (ft)	Dist from Track (ft)	Sound Levels	
								Lmax	SEL
Country Club Road									
	1	--	--	--	23	0	100	98.5	104.3
	2	--	--	--	25	0	100	99.9	104.9
	3	--	--	--	20	0	100	99.4	106.0
	4	--	--	--	16	0	100	100.4	101.5
	5	--	--	--	24	0	100	103.0	106.1
	6	--	--	--	22	0	100	95.8	99.7
	7	--	--	--	19	0	100	99.9	104.6
10th Street									
	1	--	--	--	18	0	100	95.3	100.6
	2	--	--	--	22	0	100	96.2	97.5
	3	--	--	--	21	0	100	94.8	99.3
	4	--	--	--	25	0	100	106.1	107.3
	5	--	--	--	18	0	100	104.0	107.9
	6	--	--	--	18	0	100	97.6	101.3
7th Street									
	1	--	--	--	20	0	100	93.6	106.6
	2	--	--	--	22	0	100	99.4	102.1
	3	--	--	--	21	0	100	104.5	106.8
	4	--	--	--	22	0	100	96.7	105.3
	5	--	--	--	22	0	100	98.5	105.9
	6	--	--	--	22	0	100	103.9	106.2
	7	--	--	--	20	0	100	105.3	107.6
	8	--	--	--	20	0	100	107.6	110.9
	9	--	--	--	21	0	100	101.2	102.3
	10	--	--	--	22	0	100	98.2	101.0
	11	--	--	--	23	0	100	101.6	103.1

5. Measurement Data - China Grove, NC, William Thornton Associates

Table B-5. Norfolk Southern Trains

Site	Train No.	Direc-tion	No. of Locos	No. of Cars	Speed (mph)	Dist. from Xing (ft)	Dist from Track (ft)	Sound Levels	
								Lmax	SEL
	1	--	--	--	--	660 ft	150	99.0	105.0
	2	--	--	--	--	660 ft	150	99.5	103.5
	3	--	--	--	--	660 ft	150	101.0	104.0
	4	--	--	--	--	660 ft	150	100.9	107.0
	5	--	--	--	--	660 ft	150	96.6	101.1
	6	--	--	--	--	660 ft	150	102.3	108.3

6. Measurement Data - Carrollton, TX, Harris Miller Miller & Hanson Inc.

Table B-6. Burlington Northern Trains

Site	Train No.	Direc-tion	No. of Locos	No. of Cars	Speed (mph)	Dist. from Xing (ft)	Dist from Track (ft)	Sound Levels	
								Lmax	SEL
2	1	--	--	--	--	60	235	100.0	105
2	2	--	--	--	--	60	235	99.4	109
2	3	--	--	--	--	60	235	99.6	108
2	4	--	--	--	--	60	235	100.0	109
2	5	--	--	--	--	60	235	101.0	109
2	6	--	--	--	--	60	235	95.9	102
2	7	--	--	--	--	60	235	97.7	106
2	8	--	--	--	--	60	235	99.9	107
2	9	--	--	--	--	60	235	96.1	105
2	10	--	--	--	--	60	235	97.8	105
2	11	--	--	--	--	60	235	98.2	108
2	12	--	--	--	--	60	235	98.9	108
3	1	--	--	--	--	185	220	93.4	102
3	2	--	--	--	--	185	220	97.0	108
3	3	--	--	--	--	185	220	100.0	110
3	4	--	--	--	--	185	220	103.0	112
3	5	--	--	--	--	185	220	98.8	105
3	6	--	--	--	--	185	220	100.0	109
3	7	--	--	--	--	185	220	100.0	111
3	8	--	--	--	--	185	220	98.6	105
3	9	--	--	--	--	185	220	99.0	105
3	10	--	--	--	--	185	220	95.1	103
3	11	--	--	--	--	185	220	95.4	105

APPENDIX C. GLOSSARY OF TERMS

A-weighting – A method used to alter the sensitivity of a sound level meter with respect to frequency so that the instrument is less sensitive at frequencies where the human ear is less sensitive. Also written as dBA.

Ambient – The pre-project background noise or vibration level.

Alignment – The horizontal location of a railroad as described by curved and tangent track.

Auxiliaries – The term applied to a number of separately driven machines, operated by power from the main engine. They include the air compressor, radiator fan, traction motor blower, exciter for the main generator and the boiler blower.

Ballast – Selected material placed on the roadbed for the purpose of holding the track in line and at surface.

Cab – The space in the power unit containing the operating controls and providing shelter and seats for the engine crew.

Chimes – In a locomotive horn, chime refers to the individual horns in a cluster of horns each sounding a distinct frequency

Consist – The total number and type of cars and locomotives in a trainset.

dB – *see Decibel*

dBA – *see A-weighting*

Decibel – A unit of level which denotes the ratio between two quantities that are proportional to power; the number of decibels is 10 times the logarithm of this ratio. Also written as dB.

Descriptor – A quantitative metric used to identify a specific measure of sound level.

Directivity Index – Sometimes shortened to directivity. In a free field, the difference between the sound pressure level in a given direction (in the far field of a source) and the average sound pressure level in that field.

DNL – *see L_{dn}*

DOT – The Department of Transportation. An agency of the U. S. government having jurisdiction over matters pertaining to all modes of transportation.

Equivalent Level – The level of a steady sound which, in a stated time period and at a stated location, has the same A-weighted sound energy as the time-varying sound. Also written as L_{eq}.

FRA – The Federal Railroad Administration. An agency of the U. S. Department of Transportation with jurisdiction over matters of railroad safety and research.

Frequency – Of a phenomenon that occurs periodically in time, the number of times that the quantity repeats itself in 1 second.

Hood – Refers to the coverings over the engine, main generator, and all other auxiliaries on a diesel electric locomotive. There are two hoods, one long and one short. The cab is mounted between the hoods.

Horn – An air powered warning device mounted on top of a locomotive producing high sound levels at one or more discrete frequencies.

Hourly Average Sound Level – The time-averaged A-weighted sound level, over a 1-hour period, usually calculated between integral hours. Also known as L_{1h}.

L_{1h} – *see Hourly Average Sound Level*

L_{dn} – The sound exposure level for a 24-hour day calculated by adding the sound exposure level obtained during the daytime (7 a.m. to 10 p.m.) to 10 times the sound exposure level obtained during the nighttime (10 p.m. to 7 a.m.). This unit is used throughout the U.S. for environmental impact assessment. Also written as DNL.

L_{eq} – *see Equivalent Level*

Locomotive – A self-propelled, non-revenue rail vehicle designed to convert electrical or mechanical energy into tractive effort to haul railway cars. (*see also Power Unit*)

Lead Unit – The first and controlling power unit in a series of locomotives pulling the same train.

Main Line – The principal line or lines of a railway.

Maximum Sound Level – The highest exponential-time-average sound level, in decibels, that occurs during a stated time period.   Also written as L_{max}. The standardized time periods are 1 second for $L_{max, slow}$ and 0.125 second for $L_{max, fast}$.

Noise – Any disagreeable or undesired sound or other audible disturbance.

Octave – The frequency interval between two sounds whose frequency ratio is 2.

Rail – A rolled steel shape, commonly a T-section, designed to be laid end to end in two parallel lines on cross ties or other suitable supports to form a track for railway rolling stock.

Receiver/Receptor – A stationary far-field position at which noise or vibration levels are specified.

Right-of-Way – Lands or rights used or held for railroad operation.

Root Mean Square (RMS) – The average or "mean" level of an oscillating waveform. Obtained by squaring the value of amplitudes at each instant of time. The squared values are then added and averaged over the sample time.

SEL – *see Sound Exposure Level*

Siding – A track auxiliary to the main track for meeting or passing trains.

Sound Exposure Level – The level of sound accumulated over a given time interval or event. Technically, the sound exposure level is the level of the time-integrated mean square A-weighted sound for a stated time interval or event, with a reference time of one second. Also written as SEL.

Sound – A physical disturbance in a medium that is capable of being detected by the human ear.

Spectrum - A description of a quantity as a function of frequency.

Tangent Track – Track without curvature.

Track – An assembly of rail, ties and fastenings over which cars, locomotives, and trains are moved.

Trainset – A group of coupled cars including at least one power unit.

<u>Yard</u> – A system of tracks within defined limits provided for making up trains, storing cars, and other purposes, over which movements not authorized by time table or by train-order may be made, subject to prescribed signals and rules, or special instructions.